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THE INSTITUTE OF PETROLEUM

AN Ordinary General Meeting of the Institute of Petroleum was held at 26 Portland Place, London, W.1, on Wednesday, 9 April 1952, Mr E. J. Sturgess, Member of Council, presiding.

A paper entitled "Some Observations on Corrosion in Engineering" was presented by Dr S. F. Dorey, C.B.E.

THE CHAIRMAN, introducing the author, said: This evening we have a very distinguished lecturer with us. I am sure that Dr Dorey is extremely well known to all of you. He is Chief Engineer Surveyor, Lloyd's Register of Shipping, a Past-President of the Institution of Mechanical Engineers, and a Fellow of the Royal Society. His paper is of very general interest to the petroleum industry, and we are all looking forward to hearing it.

I am asked by our President, Mr C. A. P. Southwell, to offer his apologies to Dr Dorey and to convey his extreme regret that he is not able to be here to occupy the chair this evening.

DR DOREY then presented the following paper.

SOME OBSERVATIONS ON CORROSION IN ENGINEERING

By S. F. DOREY, C.B.E.*

INTRODUCTION

CORROSION in one or other of its many forms is encountered in all branches of engineering, and in recent years considerable effort has been, and still is being, made in investigating its causes and prevention. A vast amount of literature is now available dealing with the various aspects of the subject, both from the theoretical and practical viewpoint; indeed, so much so, that corrosion and all that it implies has become a specialized subject involving a wide variety of conditions and materials. The number of corrosion research committees in different industries is indicative of the importance of the subject.

It is the purpose of this paper to present a brief survey of the subject and focus attention on the more important corrosion problems which have come within the author's day-to-day experience. While this experience naturally has a marine bias, many parallel cases will be found in other branches of engineering. It is intended to deal briefly with the theoretical

* Chief Engineer Surveyor, Lloyd's Register of Shipping.

aspect of the subject, and to stress the practical side by referring to a number of cases of corrosion and the circumstances under which they have occurred.

General

Corrosion is the wastage of metals by chemical and/or electro-chemical agencies. An example of direct chemical action is the oxidation and sulphidation of metals in dry gases, while the action of acids on metals is generally an electro-chemical action. The nature and the resistance to strain of the corrosion products, particularly if a protective film is formed on a metal, has an important bearing on the rate of corrosion.

Electro-chemical attack is the type of corrosion most frequently encountered in engineering, and it occurs under aqueous conditions, due to the formation of an electrolytic cell in which the corroding metal is anodic to another metal, or part of the same metal with which it is in contact, or to corrosion products or surface scale. For the formation of an elec-

Table I

Corroded End (Anodic, or Least Noble)
Magnesium
Magnesium alloys
Zinc
Aluminium
Cadmium
Steel or iron
Cast iron
Chromium–iron (active)
18/8 Chromium–nickel–iron (active)
18/8/3 Chromium–nickel–molybdenum–iron (active)
Lead–tin solders
Lead
Tin
Nickel (active)
Inconel (active)
Brasses
Copper
Bronzes
Copper–nickel alloys
Monel
Silver solder
Nickel (passive)
Inconel (passive)
Chromium–iron (passive)
18/8 Chromium–nickel–iron (passive)
18/8/3 Chromium–nickel–molybdenum–iron (passive)
Silver
Graphite
Gold
Platinum
Protected End (Cathodic, or Most Noble)

trolytic cell in the latter case the corrosive media must be in contact with both the metal and the scale or products of corrosion, which means there must be a discontinuity such as might be made by scratching, cracking, or flaking. This type of corrosion can be particularly severe because of its concentrated nature. In the case of different metals in an electrolyte the attack is usually referred to as galvanic action.

Corrosion can be induced under stagnant conditions, such as in cracks and pits due to a variation in the concentration of the corroding solution over the surface of the metal, and can also take place when different parts of a metal surface in contact with an electrolyte are subject to different stress conditions.

The fact that mild steel rusts more readily than pure iron is due to the fact that the ferrite and pearlite in the steel in contact with natural waters give rise to a series of short-circuited electrolytic cells, the ferrite areas constituting the anodes being rapidly attacked by the corroding medium. The homogeneity of the structure of a metal has therefore a pronounced influence on its corrosion-resisting properties. Commercial metals are never chemically pure, and small quantities of impurities tend to initiate corrosion.

Physical heterogeneity in a chemically homogeneous metal may also give rise to corrosion. Cold-worked metals, for example, are anodic to unworked metals. Corrosion is often found around punched holes in metal sheets and plates. For better resistance to corrosion, the holes should be drilled. Welded joints which have not been heat treated tend to corrode more readily than the parent metal.

Table I gives a list of metals and alloys placed in reverse order of "nobility." That is to say, a metal placed high in the list will corrode by galvanic action if placed in contact with a metal lower in the list in the presence of an electrolyte. The further apart the metals are in the list, the greater is the tendency to corrode. Metals which are grouped together are relatively safe to use in contact with each other.

Boilers

Corrosion in steam boilers takes the form of pitting, grooving, and general wastage; also cracking resulting from corrosion-fatigue and caustic embrittlement.

Pitting is the most prevalent type of corrosion found on the water-side of marine boilers. It may take the form of air blisters formed by air bubbles liberated from the boiler water attaching themselves to the metal surfaces and initiating anodic attack, due to the potential difference between the metal immediately under the bubble and the surrounding surface area in contact with the water. Another form of pitting is the formation of hard scabs which occur on the water-side of heating surfaces in boilers. These scabs comprise layers of black magnetic iron oxide covered by a cap of red iron oxide. They are associated with impure boiler water contaminated with dissolved salts. In marine boilers this contamination might be due to the presence of seawater in the feed supply. The presence of oxygen in the boiler water accelerates corrosion action which goes on underneath the scab. The attack, which is anodic in character, is

also accelerated with increase in temperature. A softer type of scab may be found in superheater tubes and in steam pipes, and is due to condensation in the presence of salt deposits which have been carried over from the boiler. Whilst this soft type of scab pitting occurs only when the boiler is shut down and condensation takes place, the harder type continues during steaming and can develop to a serious extent very rapidly.

General wastage in boilers occurs evenly over the water surfaces, but is more acute in the hotter areas. Wastage in cylindrical boilers also occurs in combustion-chamber stays and in stay tubes adjacent to the plates to which they are attached. It can be attributed to acidity of feed water, and extends with alternate expansion and contraction of the parts causing flaking of scale deposits which intermittently exposes the bare metal to

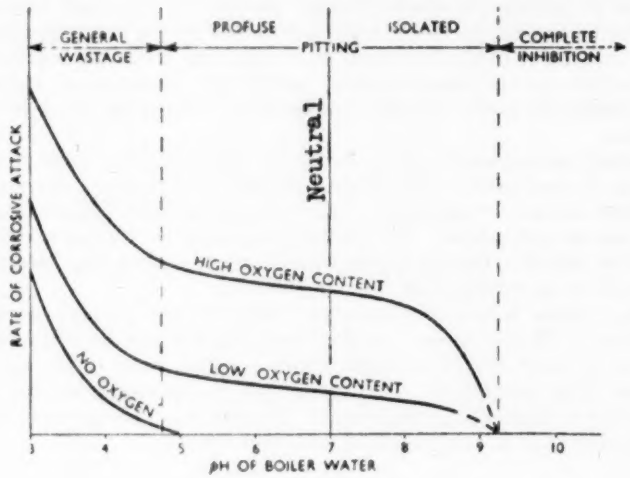


FIG 1

RELATIONSHIP BETWEEN CORROSION OF STEEL AND CONDITION OF BOILER WATER

corrosive attack. This general and local wasting can be prevented by boiler-water treatment which will ensure that the water is slightly alkaline and not acid.

Galvanic action takes place when dissimilar metals are in intimate contact in the presence of an electrolyte. Boiler water containing dissolved salts is sufficiently conductive to promote galvanic action where steel is in contact with brass or gunmetal as used in boiler mountings.

Broken mill scale on the surfaces of smoke tubes in Scotch boilers can also give rise to galvanic attack due to the potential difference between the exposed metal surface and the surface protected by the mill scale.

Since zinc is anodic to steel, it has long been the practice to fit zinc slabs inside cylindrical boilers for the purpose of protecting the metal surfaces. In recent years, however, this method of protection has given place to more scientific control by water treatment.

General corrosion takes place in the steam space of donkey boilers when not steaming but with water up to working level. It can also occur when a boiler is empty but subject to heat from a nearby boiler, particularly if the former is damp or there is a slight leakage of steam into it.

Thermal fatigue due to temperature fluctuations can give rise to cracking, particularly in boiler and superheater tubes and sometimes in the tube plates of Scotch boilers and water drums of water-tube boilers. A corrosive environment such as occurs with untreated or incorrectly treated boiler water will accelerate the propagation of these cracks.

An example of stress corrosion in cylindrical boilers is the grooving which sometimes occurs on the water-side at the internal surface of a flanged plate, such as the front end plate where flanged for the furnaces, or the neck of a furnace tube where it is flanged to form an attachment to the tube plate of the combustion chamber. The movement due to expansion and contraction of the boiler induces a stress concentration at these radii which, in the presence of even a mildly corrosive condition of the boiler water, will cause local wastage and grooving.

There is no doubt that the de-aeration of boiler feed water and proper chemical water treatment are essential for preventing corrosion in marine boilers. Fig 1 shows the relationship between the rate and extent of corrosion and the condition of the boiler water. Of equal importance, however, is the prevention of corrosion when the boiler is shut down. To fill the boiler with water would be effective if oxygen could be completely excluded, but it is doubtful whether complete exclusion of oxygen could be obtained in practice, and the addition of a chemical, such as sodium sulphate, in the water is necessary. The best practice is undoubtedly to keep the boiler empty and thoroughly dry.

Cases have occurred where serious corrosion of the internal parts of cylindrical boilers has followed drastic descaling by means of chemical fluids. The complete exposure of the metal of plates and stays by such boiler-cleaning methods makes it all the more important to exercise careful control of the condition of the boiler water.

Effect of High Temperatures

With the advent of high-temperature steam installations in ships, it is necessary to consider the possible deteriorating effects of high temperature on steel. Surface oxidation or "scaling" is a characteristic of many steels when exposed to elevated temperatures. In the case of mild steel, scaling is of a rapidly progressive character. The "scales" or oxide layers are not closely adherent to the metal surfaces, which are progressively and repeatedly exposed to the oxidizing conditions as the scales flake away. It is this progressive reaction between the metal and its environment, such as high-temperature steam over a period of time, which leads to a reduction in the dimensions of the parts exposed as, for example, in the thinning of boiler and superheater tubes.

The oxide scale produced under high-temperature conditions is hard and black, and occurs on those parts of a boiler which are subject to heat transfer, such as the fire row tubes of a water-tube boiler. The scale may form outside as well as inside the tube, and it will be appreciated that the heat-insulating effect of scale formation inside the tube in reducing the

rate of heat transfer will increase tube-wall temperature and cause a build-up of scale on the outside surfaces in contact with the combustion gases.

An example of the build-up of oxide scale in a tube of a water-tube boiler is shown in the photomicrographs (*a*) and (*b*), Fig 2. The tube, $2\frac{1}{2}$ inches O.D. by $\frac{7}{32}$ inch thick, had been starved of water for a period and the inside surface coated with a shiny black layer of scale approximately 0·025 inch thick. The dark colour of the scale indicated that heating had occurred in the absence of steam or water. Analysis of the scale showed a large amount of FeO and Fe_2O_3 and practically no Fe_3O_4, although the scale was faintly magnetic. The period of overheating had produced an intermediate condition of the oxide scale and had not been long enough to develop the pronounced triple-layer scale formation $FeO/Fe_3O_4/Fe_2O_3$. The metal temperature had obviously exceeded 575° C, and the photomicrograph (*b*) shows the crystalline nature of the outer layers of scale. Photomicrograph (*a*) shows the junction of the scale and steel unetched.

For high-temperature service the use of carbon–molybdenum steel for superheater tubes, steam pipes, and fittings will minimize scaling effects and provide considerably better tensile properties than mild steel at elevated temperatures. For better scaling resistance, however, also for use at higher temperatures up to 1000° F (538° C), a chromium–molybdenum steel (1·0 Cr, 0·4 to 1·0 Mo) must be used.

External Corrosion of Boilers

A frequent source of external corrosion of boilers is the accumulation of fuel deposits on fire-side components, particularly on tubes at positions where accessibility for cleaning is difficult. These deposits invariably contain sulphurous compounds, which, in the presence of moisture, can form free sulphuric acid. This acid corrosion will continue so long as a boiler is shut down and damp. Under steaming conditions, however, the deposits are dry.

Coal, boiler oil, and diesel oil all contain sulphur to a greater or less degree, but in themselves are not usually corrosive. A quantity of sulphur dioxide is contained in the products of combustion, and this is harmless so long as the temperature of the gases remains above the dew point. A corrosive sulphurous acid is formed following condensation when the temperature falls below this point. Such conditions do arise in air heaters, economizers, and in the exhaust manifolds of oil engines.

In addition to the effect of sulphur in fuels, the ash formed on combustion can provide a serious cause of corrosion. The composition of ash varies with different fuels, but when it has a high vanadium pentoxide content it will, whilst in the liquid state, attack metals which are normally oxidation resisting.

Caustic Cracking

Laboratory experiments have established that high local stress in the steel combined with a high concentration of caustic soda (sodium hydroxide) are the primary causes of caustic cracking in steam boilers. The phenomenon is still, however, imperfectly understood. Features of this type of cracking

are that the cracks are intercrystalline in direction; they usually start at rivet holes, and occur at the faying surfaces of lapped or strapped seams. Where the feed water of marine boilers is treated with soda, leakage at riveted seams brings about a concentration of caustic in the interstices of the joints. It has been established that concentrated caustic soda will attack steel which is under stress, the rate of attack increasing with stress concentration, but being little affected by increase in temperature.

It is claimed that caustic cracking can be prevented by chemical means, notably by the presence of sufficient sodium sulphate in the boiler water. Limiting ratios of sodium sulphate to caustic soda have been laid down by

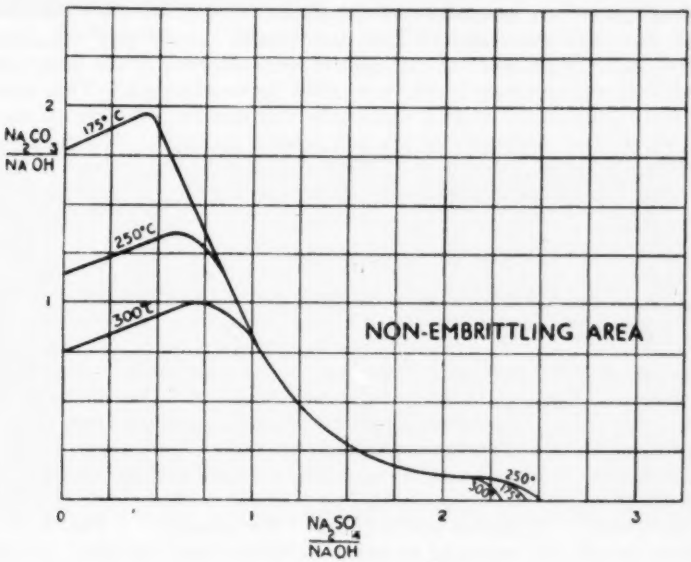


FIG 5

CURVES SHOWING RATIOS $Na_2CO_3/NaOH$ AND $Na_2SO_4/NaOH$ REQUIRED IN BOILER WATER TO PREVENT CAUSTIC EMBRITTLEMENT

various authorities with a view to preventing caustic attack, that suggested by BS 1170 : 1947 being based on fairly substantial evidence. The use of tannin, and certain organic compounds closely related to tannin, and sodium nitrate have been tried out as inhibitors with a certain amount of success.

Fortunately, caustic cracking is not frequent in marine boilers, but advanced cases have occasionally been found. It is usually detected at a boiler survey by indications of leakage at riveted seams, and by rivet heads breaking off when tapped with a hammer. These outward manifestations, however, occur only when caustic cracking is already so far developed that major repairs are required to put the boiler in safe working condition.

Caustic cracking may affect all or any of the riveted seams in a boiler—longitudinal, circumferential, furnace, combustion chambers, compensating

rings, mounting pads, etc.—and may be found in both fire-tube and water-tube boilers.

Cracking starts at the faying or contact surfaces of riveted seams and radiates from the rivet holes. It is not until the trouble is well developed that the cracks reach the outer surfaces of the plates forming the joint, by which time cracks may have extended from rivet hole to rivet hole, Fig 3, and attained dangerous proportions. Cracks also occur in the rivets, generally under the points and heads, also occasionally at the lines of plate separation, Fig 4.

The cracks have the characteristic that they are mainly intercrystalline, a feature which can be established only by microscopic examination of a polished and etched sample of affected plate.

The American investigators Parr and Straub carried out experiments to show that the presence of sufficient sodium sulphate in the boiler water was all that was necessary to prevent attack by caustic soda. They worked out limiting ratios of sodium carbonate and sodium sulphate to caustic soda which were necessary to prevent caustic cracking. These ratios are shown in Fig 5, and if the values of these ratios in the boiler water lie within the curve, it is claimed that caustic attack will not occur.

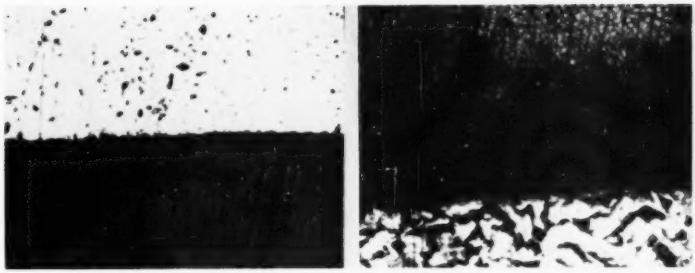
Machinery

Steam-turbine cylinders do not normally present any problem as regards corrosion, and are usually made from iron or plain carbon-steel castings, except where very high temperatures are involved and a carbon–molybdenum steel casting becomes necessary. Turbine blading, however, is required to withstand more rigorous conditions in operation, and must possess not only adequate strength at the working temperature, but also high resistance to oxidation, corrosion, and erosion. Stainless steels and high-nickel non-ferrous alloys are normally used for turbine blading.

The most widely used turbine-blading material is 13 per cent chromium–low carbon steel, frequently referred to as " stainless iron." The chromium content enables the material to resist oxidation and corrosion, except in the presence of chlorides. Careful control of operating conditions and boiler-water treatment are required in power-stations and on board ship to avoid chloride contamination of steam. In some industrial plants the presence of chlorides in the steam cannot be avoided altogether, and in such cases it is usual to employ an austenitic steel, or high-nickel non-ferrous alloy for turbine blading.

The importance of adequate drainage of pipes, cylinders, air reservoirs, valve bodies, etc., where moisture would otherwise accumulate had been demonstrated in a number of cases brought to the author's notice in which severe corrosion has occurred either because drains were not provided at the most suitable positions or because, when they were provided, they were not properly used. Fig 6 shows the form of wastage found to occur in certain types of cast-steel safety valves in which condensate was allowed to accumulate around the nozzle due to insufficient drainage.

Drainage openings themselves provide a focus for corrosive action, especially when drain valves are only used intermittently. Positioned, as they should be, where water is most likely to collect, they are specially



(*a*) Unetched. × 100 (*b*) Etched in 20% nital. × 100

FIG 2

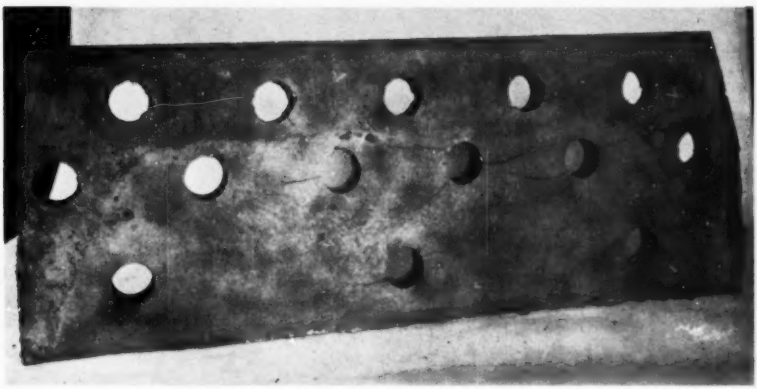


FIG 3

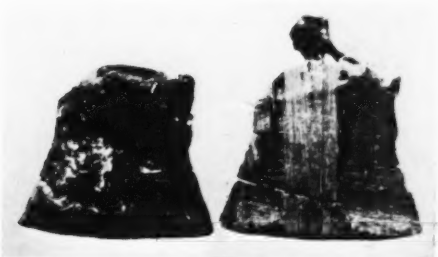


FIG 4

[*To face p.* 892.

Fig 7

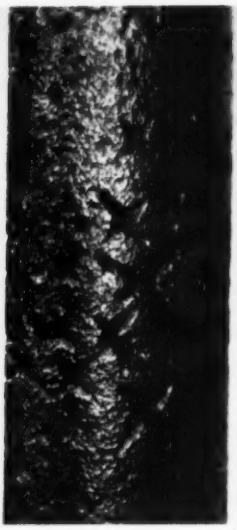


Fig 8

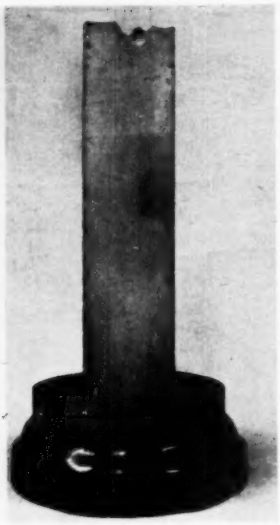
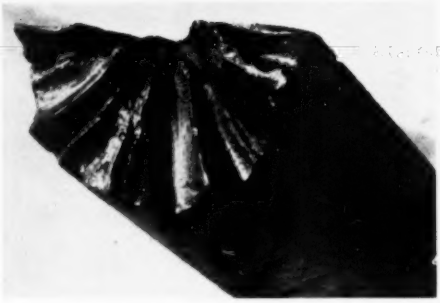


Fig 9

Fig 10



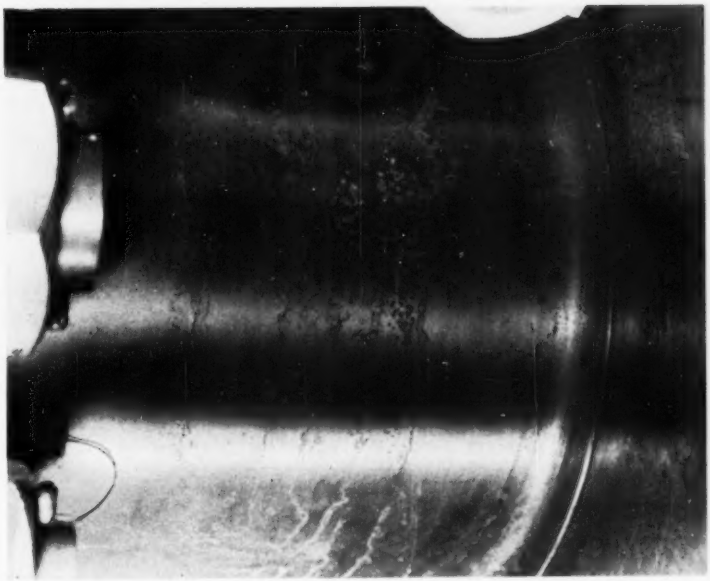


Fig 11

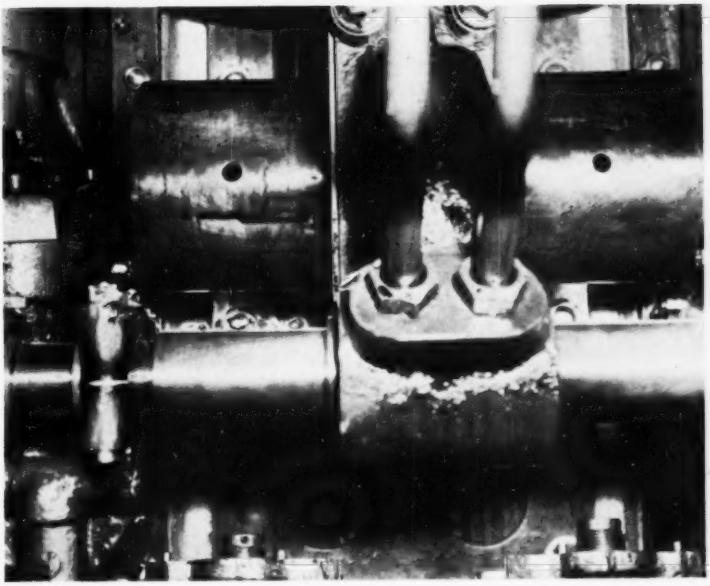


Fig 12

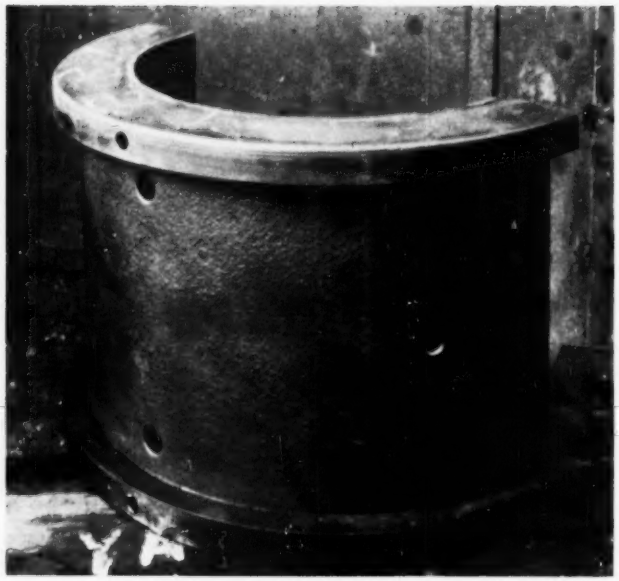


FIG 13

FIG 14

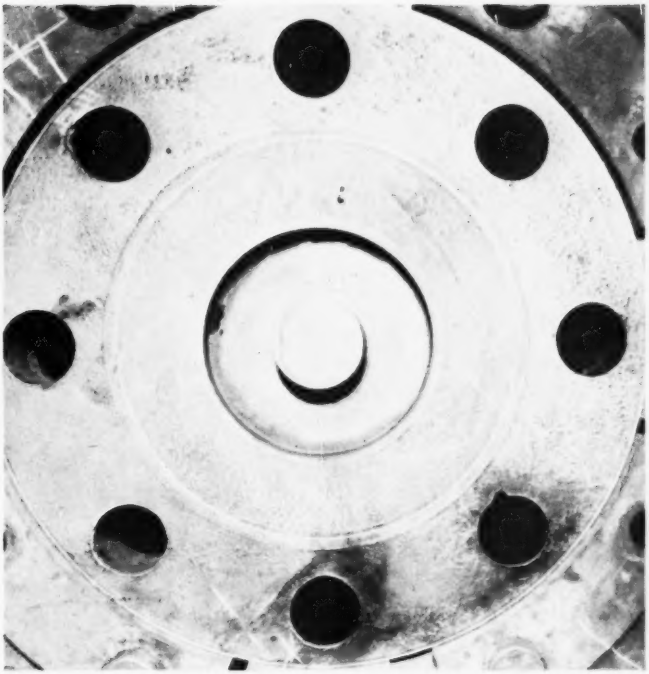


FIG 15

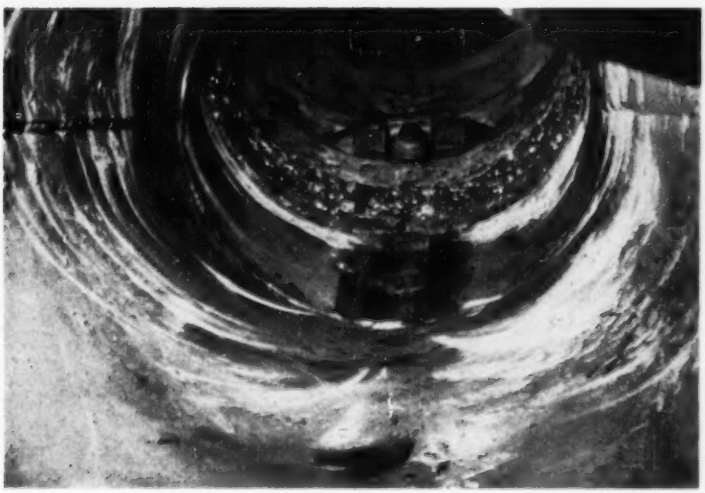


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FIG 16

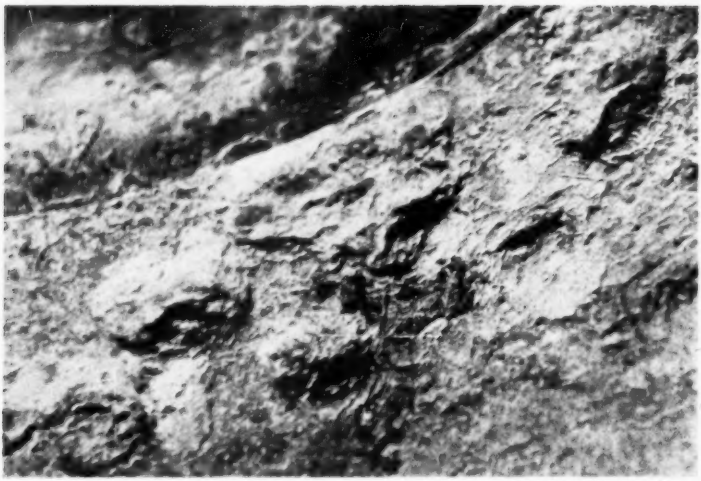

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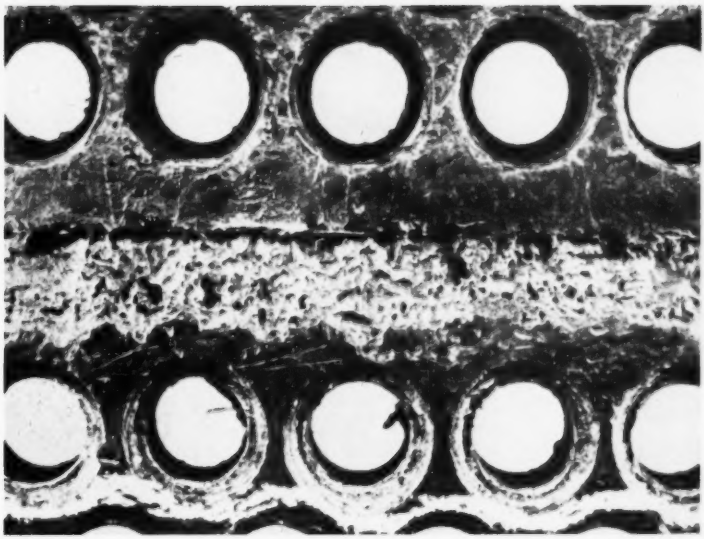
FIG 17

Courtesy, Institute of Metals

FIG 18

Courtesy, Institute of Metals

FIG 19



Courtesy, Institute of Metals

FIG 20

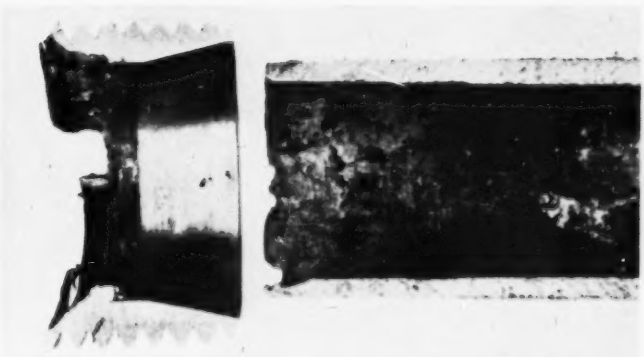


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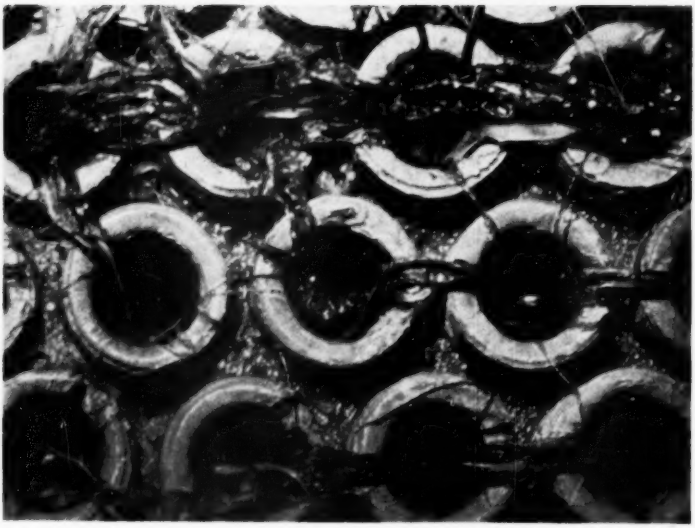
FIG 21



Courtesy, Institute of Metals

FIG 22

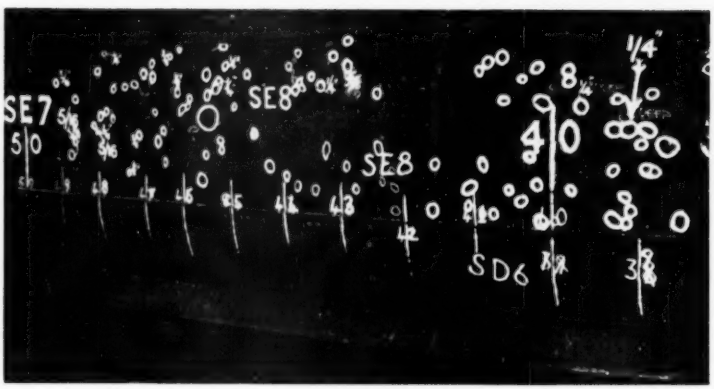


FIG 23

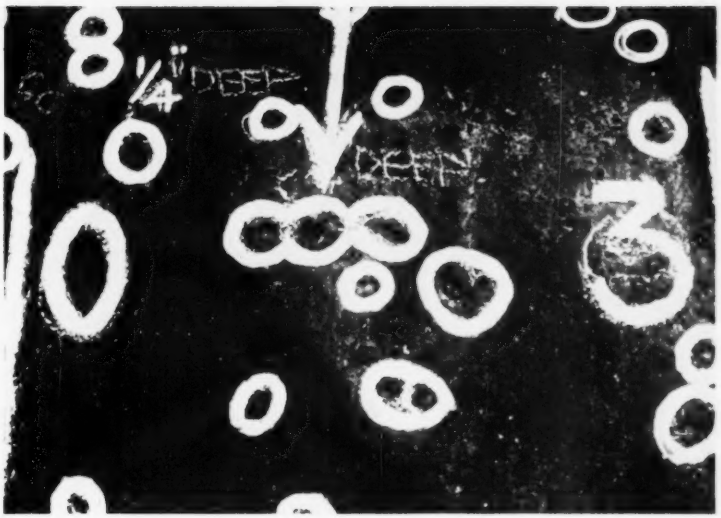


Fig 24

Fig 25

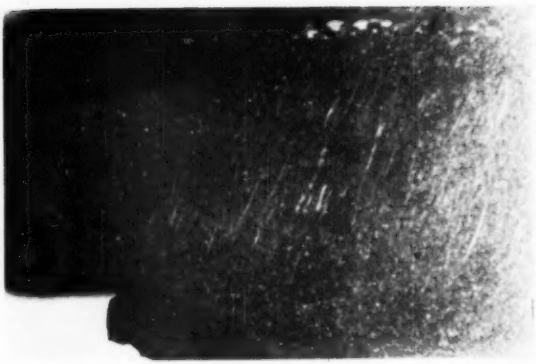


Fig 26

Fig 27

Fig 28

vulnerable to attack, and should be carefully examined when inspections are carried out.

Marine Shafting

The most serious defects encountered with propeller shafts are associated with corrosion-fatigue. The methods adopted to exclude seawater from access to the shaft are not always completely successful, and once the attack is commenced and a corrosion groove formed in the periphery of the shaft, a condition for failure by fatigue is established.

The effect on the strength of metals through the combination of corrosion and cyclic stress has been shown by a number of investigators to produce much greater accelerated damage than would be the case with stressless corrosion, corrosion with static stress, or failure under cyclic stress applied in a corrosion-free environment. The corrosion-fatigue effect is not due

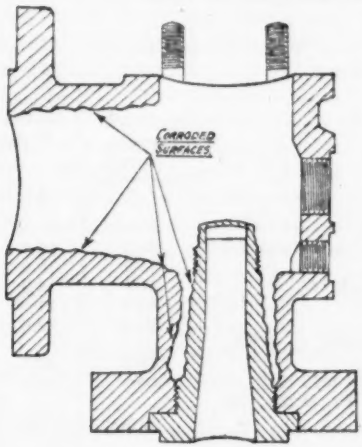


FIG 6

to the reduction of section caused merely by general corrosion, nor to the presence of deep holes formed by local attack, but is primarily due to the sharp, deep pits or fissures produced under this joint action. A factor of primary importance in this combined process of destruction is oxygen, and for the exclusion of oxygen it is necessary to exclude water in which it is dissolved. It will also be apparent that at parts in contact with water where excess of oxygen is present as, for instance, at the ends of the brass liners on screwshafts, where, owing to discontinuity of form, eddying takes place, the corrosion in the vicinity will be more severe owing to the greater differential aeration.

It would appear that cyclic strains induced by cyclic stresses, rupture, or make more permeable, a surface film which protects the material from corrosion. This film may possibly be that formed by the corrosive medium itself. Where corrosion has taken place before cyclic stresses are imposed, the induced cyclic strains will dislodge the corrosion products and lay bare a fresh surface for attack.

This surface film is an invisible oxide skin, by which is meant the entire primary layer affected by contact with the corrosive medium, including not only the oxide layer but also the underlying layer of metal into which oxygen or other negative element has penetrated. If the cyclic strains are imposed at a slow rate it is possible for the surface film to be built up and protect the surface from corrosion during the cyclic interval, or there may be present an oxidizing agent in sufficient quantity to repair the film even at high frequencies.

The peculiar property of stainless iron and stainless steel is that the surface film is less permeable than the films on ordinary steels, and when ruptured is capable of building up an oxide film which can be kept in repair by dissolved oxygen.

The results of a few experiments extracted from a larger number carried out by McAdam on steel specimens subjected to corrosion fatigue in three different environments are given in Table II.

TABLE II

Steel	Ultimate tensile strength, tons/sq. in.	Stress, tons/sq. in., for unbroken specimens subjected to approx 5×10^7 cycles		
		Air	Fresh water	Salt water
0·16% C steel (hardened and tempered)	29·3	16·0	8·9	4·0
0·24% C steel	24·8	10·0	7·6	—
Copper steel 0·98% Cu, 0·14% C	27·5	14·3	8·9	3·5
1·09% Carbon steel	46·2	17·85	9·4	—
3·7% Ni steel	40·5	22·0	10·1	7·1
Ni–Cr steel (1·5% Ni, 0·73% Cr, 0·28% C)	62·0	30·3	7·2	6·2
Stainless iron (12·9% Cr, 0·11% C)	40·0	24·5	17·0	13·0
Stainless steel (14·5% Cr, 0·23% Ni, 0·38% C)	42·0	23·2	16·0	16·0

The fresh water used in the experiments was calcium carbonate well water, the salt water having a saline content of about one-sixth that of seawater. It will be noted that there is an appreciable reduction in fatigue strength when the specimen under test is sprayed with water, and the corrosion-fatigue values of the alloy steels, although of increased ultimate tensile strength, indicate that from a design point of view their extra cost would not be justified. Since subsequent propagation of cracks depends largely on stress-concentration effects of the crack when cyclic stressed, it may be that cracks developed in the higher-tensile steels are finer than for low-carbon steels, and hence permit greater rapidity of propagation, particularly if it may be assumed that *initial* corrosion takes place at grain boundaries. It has been suggested that to increase the strength of screwshafts the surface should be cold worked. While this will increase the normal fatigue resistance of the material, it renders it more liable to fracture by corrosion-fatigue due to its apparent increased notch sensitivity, that is, once a crack is formed it is propagated more rapidly.

The corrosion-fatigue values given in Table II were obtained with high cycle frequencies, namely, 1450 per minute, so that the actual period for corrosion was comparatively small. Very considerable damage can be caused either by small ranges of stress continued for a sufficiently long time or large ranges of stresses at slow frequencies. Inglis and Lake, testing a mild-steel specimen, found the bending-endurance limit when tested in air to be about ± 17 tons/sq. in., but when exposed to simultaneous alternating stresses of $\pm 2{\cdot}6$ tons/sq. in. and drips of River Tees water having a salinity of about two-thirds that of seawater, the specimen broke after $66{\cdot}4 \times 10^6$ reversals. To give a life of 10^8 reversals it was estimated that the stress would be about ± 1 ton/sq. in. From this, and other similar experiments, it would appear evident that for ordinary commercial steels there is no corrosion-fatigue limit and, given sufficient time, failure will occur under very low stresses.

When it is to be remembered that the shafting of a ship in service for 240 days a year rotates about 30 million times yearly with engines having a speed of 100 r.p.m., and that the specimens used in the foregoing tests were polished and of plain cylindrical form, the need for special care to prevent the access of seawater to stressed parts, and particularly at points where there is a likelihood of stress concentration, is obvious.

Fig 7 shows the failure of a steel propeller shaft caused by water passing the packing ring between propeller boss and end of shaft liner, and obtaining access to the neighbourhood of the keyway. The 15-inch-diameter shaft had been in service for four years, and failed through corrosion fatigue which commenced at the bottom of the end of the key seat, continued around the section of it, and then spread out to the periphery, joining up with subsequent corrosion cracks on the periphery. As a practical demonstration of the notch sensitivity of the material caused by this crack, it may be noted that the shaft broke at the second blow from a 5-cwt weight dropped about 40 inches away from the crack on the coned end from a height of 20 ft.

Figs 8, 9, and 10 show three different views of a broken mild-steel shaft, of $4\frac{3}{4}$ inches diameter, which is as good an example of torsional corrosion-fatigue as one would wish to avoid. The shaft, taken from a river tug, had been running at or near a critical speed for a period of several weeks. This situation was made considerably worse by the fact that the shaft passed beneath the floor-boards of the after cabin. Persistent leakage from the stern-tube had occurred on account of the outboard oil-retaining gland having been damaged, and the resulting accumulation of seawater set up corrosion in the after portion of the shaft. This in conjunction with the torsional vibration stresses present during operation was sufficient to cause failure after a few weeks service. This example demonstrates the serious consequences that may arise from neglect of torsional-vibration characteristics of a shafting system at the design stage.

In this particular instance the cure was the avoidance of the critical speeds in service and elimination of the corrosive environment of the shaft.

Oil Corrosion

A specially virulent type of corrosion occasionally occurs on the pins and journals of crankshafts. This is caused by contaminated lubricating

oil. It is found that the oil deteriorates after some length of service, due to atmospheric pollution, seawater leakage, and the leakage of combustion products from the cylinders of oil engines. The corrosive deterioration of the oil is cumulative, and depends on a number of factors, such as length of service, fuel with which it has been associated, and the moisture content of fuel, air, etc.; also the presence of catalysts, such as copper components. The engineer can, however, do quite a lot to prevent deterioration of lubricating oil by providing thorough filtration, by separating piston lubrication from crankshaft lubrication, and by paying proper attention to methods of storing and replenishing lubricating and fuel oils. Unfortunately, the formation of acid in the cylinders of oil engines cannot be entirely prevented, and leakage into crankcases through worn piston-rings and cylinder-liners will occur to an extent, depending upon the condition of these parts.

New oils on test are usually non-corrosive, but used oils taken from lubricating systems in motor ships are invariably found to contain water with acid reactions. Corrosion tests on used oils have shown that the addition of water causes the corrosive action of oil to be slightly more severe than when no water is present, that caustic treatment of a non-corrosive oil causes it to become corrosive, and that the corrosion effects of small amounts of seawater in the oil are of different character from those produced by oil contaminated by the products of combustion.

Corrosion of crankshafts by contaminated oil may be less serious and in practice certainly less frequent than the corrosion of screwshafts by seawater, but in both cases the final effect is to reduce the fatigue endurance of the shaft.

Typical examples of corroded crankshaft and crosshead bearing surfaces are shown in Figs 11 and 12.

Similar corrosion has been known to occur in the bearing surfaces of marine steam-turbine rotors when a very small amount of seawater has contaminated the lubricating oil. It has been found that corrosion inhibitors in lubricating oil, whilst effective in normal circumstances, do not necessarily prevent corrosion by seawater, and that once corrosion has commenced from this cause salt is retained in the microscopic pits in the steel and continues the corrosion action, even after the oil has been cleaned or renewed. This is not to say that the development of corrosion-inhibiting lubricating oil has not gone a long way in the protection of bearing surfaces. The protective efficiency of an oil is greatly increased by the addition of inhibitors which promote the formation of a molecular film on the steel, thus hindering contact between steel and water.

In general, water droplets in contact with working surfaces are mechanically displaced by the oil when an engine or turbine is running, but when the machinery is at rest the relative immunity of the working surfaces disappears and water marks on journals, etc., result from the presence of any considerable amount of water in the oil.

Salt water causes disruption of the protective oil film far more readily than does fresh or distilled water, and once corrosion has begun, the renewal of a protective film of oil may be prevented. It appears, therefore, that it would be unsafe to rely on corrosion-inhibiting oils to ensure protection after contaminated water has entered the lubricating-oil system.

The use of sodium nitrite mixed with the lubricating oil, and in the form of a paste for protection during laying-up periods, has been found to be an effective means for arresting corrosion.

Fretting Corrosion

Fretting corrosion may be found when separating the contact surfaces of tightly fitting machinery parts which have been subjected to cyclic stress, and some microscopic relative movement has taken place between them. Among such parts are keyways, spline fits, ball-race housings, claw and plain couplings, engine bearings, connecting-rods, and so forth. The first visible signs of trouble where steel surfaces are concerned is often the appearance of rusting oil or a cocoa-coloured deposit.

Investigations have shown that this form of corrosion always occurs on surfaces held together with sufficient intensity to ensure adequate metallic contact, and subjected to slight alternating relative slip together with the presence of some agent, such as air or moisture, from which oxygen can be derived. It does not occur when there is alternating surface stress without actual slip.

Fretting corrosion is caused by the tearing away of minute metallic particles from the surfaces in contact, and can be recognized by the oxidized powder which results. It is, in fact, a friction oxidation, the first stage being mechanical attrition, and the second, chemical. This form of corrosion causes intense local stress concentration, and taken in conjunction with the effects of clamping stresses, such as produced by " shrink fits " and press fits of wheels on axles, crank-webs on shaft journals, liners on shafts, may cause substantial reduction in fatigue strength.

In general, contact surfaces of the same material are more liable to attack than those of different materials, and lubricated surfaces are less susceptible than dry ones, since the presence of lubricating oil reduces the rate of oxidation. Surfaces having the same degree of finish are more affected than those having varying degrees of finish, while with hard surfaces fretting corrosion takes place easier than with soft surfaces, which are more liable to seizure. The natural protective surface of steels in contact can be improved by phosphating, which forms an additional film to prevent metallic contact.

An interesting example of fretting corrosion is shown in Figs 13 and 14. These show a crankshaft main bearing and housing in the bedplate of a marine oil engine. The bearings had not been properly hardened down, with the result that the normal vertical forces on the bearings, together with the flexing of the crankshaft due to bending, had caused sufficient relative movement between the bearing bottom halves and the bedplate housings to bring about fretting corrosion to a total extent of $\frac{40}{1000}$ to $\frac{60}{1000}$ inch in about sixteen months of service. In all cases the depth of corrosion was found to be greater at each end of the bearings than at the centre, indicating that slight rocking action had taken place. This case emphasizes the importance of ensuring that, when lining up a crankshaft, the shaft bearings are hard down in their housings.

In this engine the top and bottom flange faces of the connecting-rods were also found fretted, indicating that slight movement had taken place between the connecting-rods and the top- and bottom-end bearings.

Another example is shown in Fig 15, where the face of a shaft-coupling flange has suffered from frettage corrosion action.

Corrosion in Oil-process Plant

It is unusual to find corrosion with cold crude oil, except when water is present. Instances have occurred where corrosion has been found below sludge, but it is probable that water was present.

In stabilizing units, H_2S is the main corrosive agent in the form of $H_2S{\cdot}6H_2O$. Pitting is sometimes severe in the shells of vapour condensers, and slight but more general wastage occurs in reboilers, where, in addition, selective corrosion of the internal welding of branches has been observed.

Stabilizing units are sometimes used on distillation duty, when, due to the breakdown of chlorides, an aqueous solution of hydrochloric acid may be formed wherever condensation takes place. Corrosion is found to be heaviest around the bottom head of water drain traps. In distillate accumulators, branches on the upper part of the shell have corroded whilst the vessel shell adjacent has shown no marked attack. This may be due to condensation resulting from temperature differences between shell and nozzle. Cement lining of the lower part of the vessel has been found to afford effective protection. It is, of course, essential that the lining should be intact, and should be completely renewed if found cracked or damaged.

An interesting case of corrosion attack on the safety valves of degassing separators was recently brought to the author's notice. The safety valves concerned were attached directly to three degassing separators, and a common manifold was provided on the outlet side. This was carried away from the station area to a burning point by means of a downward-inclined pipe. A connexion was made to this pipe, remote from the safety valves, of the drains from tundishes associated with sampling cocks on the crude-oil lines.

During an overhaul of the valves, on removal of the external springs and covers it was found that the high-lift pistons and the spaces between piston and upper part of the valves were heavily corroded. It was necessary to drive the valves from their seats, but examination of the sealing faces showed no signs of leakage. When rust and scale had been removed it was found that there had been severe corrosion attack on the cast-steel valve bodies and that the stainless-steel internals were deeply pitted.

The most likely explanation of this external attack on the valves is that, following drainage of crude oil into the manifold, gas was released which had been driven back towards the safety valves under certain wind conditions. The valves were of the external spring type, and the spindle hole in the cover was of large diameter. Rain had thus penetrated to the top of the balance pistons, whence it had drained, through a drain hole provided, to the space between pistons and valves, and there became contaminated with H_2S gas.

Possibility of recurrence was prevented by removing the manifold completely and allowing the safety valves to vent directly to the atmosphere.

Corrosion caused by crude oil in fields and in topping and cracking units in general occurs as follows :—

(1) In the fields, hydrogen sulphide present in the crude oil causes corrosion, particularly of storage-tank roofs.

(2) In the topping units, corrosion is caused by the hydrolysis of chloride salts, particularly magnesium chloride, the areas chiefly affected being the last few tubes in the heater, transfer lines, and flash section of the fractionating column.

(3) In the cracking units, corrosion is mainly caused by sulphur compounds in two distinct areas, (*a*) in hot regions (700° to 800° F), and (*b*) in cold regions in the presence of water.

A special case occurred at one refinery where some crude oil was imported from a different part of the world, and corrosion was experienced in the heavy gas-oil section of the fractionating column of the topping units, perhaps caused by naphthenic acid present in this crude oil. The corrosion was interesting in that it particularly attacked regions of high local stress, in this case the 5 per cent Cr alloy bubble caps where the spacer pieces were spot welded into the caps. A further principle was also clearly shown at the same time, namely, that bubble caps made from cast iron stood up to the corrosion attack far better than the alloy steel, thus demonstrating that each corrosive environment must be considered on its own merits.

An example of corrosion not necessarily confined to the oil industry may be experienced with strong sulphuric acid, where no perceptible corrosion is normally expected. At places of high turbulence such as elbows, tees, valves, etc., heavy corrosion may occur due to the high velocity removing the protective coating of ferrous sulphate.

Examples of Corrosion Due to Seawater

Corrosion by seawater is influenced not only by the properties of the metals and the chemical constituents of the water, but also by the speed of flow and the degree of turbulence which takes place.

An example is shown in Fig 16, where a steel seawater inlet tube fitted in a ship's side plating has been attacked by the inflowing seawater. The rust marks indicate turbulence and a rotary motion of the water stream.

In addition an adjacent gunmetal valve adjoining the sea-inlet tube has promoted severe wastage of the rivet heads securing the tube to the ship's side plate, Fig 17.

The gunmetal valve may be fitted with a valve spindle made of a less noble metal such as rolled naval brass. In contact with seawater this arrangement can lead to serious dezincification of the spindle and wastage by impingement attack. An example is shown in Fig 18.

Fig 19 shows a phosphor bronze seawater pump impeller which has suffered corrosive and erosive attack on the vanes by direct impingement accompanied possibly by sand and, to some extent, cavitation erosion. The use of more noble metals, such as monel or stainless steel, for impellers might, due to their cathodic nature, endanger adjacent parts, including the pump housing.

An interesting example of attack by seawater moving with local high velocity and turbulence is shown in Fig 20, where corrosion of a rolled naval-brass condenser-tube plate has occurred in way of the division plate,

which had not been fitted closely abutting the tube plate. Thus some of the seawater had by-passed the first section of the condenser, through the narrow gap between the plates.

Corrosion of brass condenser ferrules is not unknown, see Fig 21. Due to the spread of corrosion products, the adjacent and more resistant material of the tube has also been affected. Weed entanglement at the tube inlets, see Fig 22, is also conducive to corrosion by abrading the protective film on the ferrule metal, thus exposing the metal to impingement attack.

Seawater corrosion is, of course, an ever-present problem in the preservation of ships' hulls, Figs 23 and 24. The major contributing factor is mill scale on the plates. The mill scale is cathodic to steel, so that if it is not completely removed corrosion is bound to occur at the boundary between scale and base plate.

Unfortunately in practice it is rarely possible to effect complete removal of mill scale from ships' plating prior to first painting, and in general reliance is placed on weathering and wire brushing. In the course of time the normal straining of the hull plates flakes off adhering scale, together with the paint, and thereafter regular docking and painting ensures protection against further wastage.

A type of corrosion, which under suitable conditions can be severe, is that caused by microbiological bacteria known as *vibrio de sulphuricans*. It occurs in buried steel or iron pipes, and on the hulls of ships which rest on mud in estuarial waters.

This bacteria flourishes in suitable soil or mud, and in order to thrive requires an environment containing sulphates, organic matter, and moisture. There are two types of bacteria in this group, one of which acts upon the sulphur-containing organic matter, producing free sulphuretted-hydrogen gas, and the other reduces sulphates to sulphides.

A feature of this type of bacterial corrosion is that it occurs under anaerobic conditions (*i.e.*, in the absence of oxygen). The corrosion product is not rust, but contains black sulphide of iron. In normal corrosion dissolved oxygen, by depolarizing the corrosion cells, promotes corrosion. When dissolved oxygen is excluded, the oxygen made available by the bacterial reduction of sulphates is able to carry out the depolarization. Thus the bacteria promote a corrosion reaction which would otherwise be suppressed, due to oxygen deficiency.

An interesting case of bacterial corrosion of a new ship during the time she was fitting out following launching has recently been described by Dr Patterson. Severe corrosion of the external hull took place over a period of about seven months, the vessel lying in a tidal river and part time resting on mud polluted with organic matter from sewage, etc. The periodic reversal flow of contaminated water and high day temperatures of shell plates contributed to a speeding up of the attack by facilitating growth and development of the bacteria.

The corrosion, which was all below the water-line, took the form of pitting on the rivet heads and extensive pitting join-up to form grooves both in the fore and aft direction and vertically on the plating, being most severe on projecting surfaces, *i.e.*, outer strakes of plating and their rivets.

A somewhat similar case was investigated some five years ago, and related to the manganese-bronze propellers of a launch which was sheathed

with copper. There were three propellers, and the starboard propeller was very badly corroded, being partly embedded in mud at low tide, corrosion in anaerobic conditions being maintained by the presence of sulphate-reducing bacteria from sewage. The original metal contained 59 per cent Cu, 39 per cent Zn, and 1·9 per cent Mn, whereas analysis of the corroded portion gave 85 per cent Cu, 5·3 per cent Zn, and 0·22 per cent Mn.

In certain rivers wood craft, where the bottom is copper sheathed, have shown rapid deterioration, but if the sheathing is of Muntz metal very little deterioration takes place. Electrolytic action is also so active in certain waters that yacht-builders have found it more prudent to fit gunmetal propellers. In another case of a yacht moored in the Hamble River astern of a boys' training ship, pitting of the propeller and shaft was considered to be due to the yacht lying in the sewage stream from the training ship.

Perhaps more severe than the corroding of the plating of ships' hulls is the corroding of rivet points. There are several factors which may account for this. Worked material is anodic to unworked material, and there is no doubt the hammering of rivet points leaves the rivet material in a state of strain which causes it to be a small anodic island surrounded by a comparatively large cathodic area. A further influence is the possible formation of anodic and cathodic areas in the rivet point itself due to the hammering in of scale formed when the rivet is heated. This would lead to a honeycomb type of pitting of the rivet point.

Again, rivet points stand proud of the surface of the plate and are therefore liable to abrasion by rubbing on dock wharves, etc. In this way the protective paint is removed, exposing the points to corrosive attack.

So far as ocean-going ships are concerned, the tanker presents the most difficulty, for in this case not only has the outside hull to be protected against corrosion and anti-fouling, but also the cargo tanks. The alternating cargoes of oil and seawater—the latter for ballast—are largely responsible for the rapidity of the corrosion, and petrol bulk cargoes are more corrosive than those of the heavier oil fuels. A process of electrolytic descaling of petrol and oil-fuel tanks has been tried out in the U.S. by applying heavy amperage current to an arrangement of anodes suspended in the tanks, soluble anodes of mild steel being used, with practically no hydrogen and detectable chlorine being produced. Research is also being carried out on the use of cementiferous paints made with a base of zinc dust and certain chloride solutions, as they are unaffected by petrol and oils. These paints, unfortunately, are disintegrated by seawater, but can be used as primers and covered with an organic sealing coat. Their effectiveness will depend on the continuity and thickness of the sealing coat or coats.

Dezincification

Dezincification of brasses is an electro-chemical process which is believed to involve both selective corrosion of the zinc in the alloy and also the solution and re-deposition of copper. The cathodic reaction can occur in the absence of oxygen and without any apparent change in the dimensions of the part attached, which is left in the form of a spongy copper devoid of zinc.

Susceptibility to dezincification increases with zinc content, and alloys

containing less than 15 per cent zinc are practically immune from attack. Other alloying elements, such as silicon, aluminium, tin, arsenic, iron, and manganese, influence susceptibility. Tin and arsenic have an inhibiting effect, whilst iron and manganese are harmful.

Brasses normally used in engineering can be single-phase α solutions or duplex $\alpha + \beta$ solutions. Single β-phase brasses are also produced, but are of limited use in engineering. Zinc content largely governs the phase of any particular composition. From a corrosion point of view the essential difference between α and $\alpha + \beta$ brasses is that the former are solid solutions of zinc in copper, whilst the latter are two-phase alloys. A two-phase $\alpha + \beta$ alloy, because of its heterogeneity, will be more susceptible to electro-chemical attack than a single-phase α brass. The latter, however, is not entirely immune.

An outstanding example of dezincification occurred in the bronze propeller shaft of a yacht which was investigated by the author's research staff.

It will be evident from the illustration, Fig 25, that intense " corrosive " attack had taken place at a position roughly $\frac{3}{4}$ inch forward of the forward end of the keyway. The disintegration had been so complete that the shaft appeared to consist of two parts, a " core " and a " sheath." Some discoloration was evident on the taper portion, two areas being copper coloured. The same discoloration was evident in and near the forward end of the keyway, extending up to and into the fracture. (The actual fracture across the keyway was due to sawing and subsequent breaking.) The " core " and most of the cracked and exposed inner surfaces also had this copper colouring. The missing portions from the " core-like " area were not included in the photograph. The " walls " of this area showed surfaces very similar to the usual type of fatigue fracture, and were mainly copper coloured and interspersed with numerous cracks or fissures.

Drillings taken from the outer detached portion and also from the centre of the shaft gave the following analysis :—

	Cu	Sn	Pb	Zn	Fe	Mn	P
Centre . .	68·8	trace	trace	23·59	1·20	4·48	0·012
Outside . .	91·96	trace	trace	2·72	0·14	trace	0·086

Fig 26 shows a view of the aft portion of the core at a magnification of 3. It will be seen that the shaft in this area consists of four zones : (*a*) the area near fracture, copper coloured and containing numerous cracks; (*b*) the outside portion, brass coloured, and apparently fine grained; (*c*) an intermediate zone of very large crystals in varying tones of yellow; (*d*) the main central portion.

Hydrogen Attack in Steel

Certain processes in oil refining and in the chemical industry have been found to promote corrosive reactions at the surfaces of steel vessels which generate atomic hydrogen. Hydrogen in this form diffuses into the steel, producing embrittlement and " blistering." It has also been found that the rate at which hydrogen diffuses through steel is greater in steel having residual stresses, such as may be due to cold work or welding, than in steel having low internal stress.

The appearance of blisters in steel is positive evidence of hydrogen attack.

It is understood that the formation of blisters is due to the conversion of atomic hydrogen into molecular hydrogen. These conversions take place at segregates and discontinuities within the steel, and are accompanied by a tremendous increase in volume. High gas pressure is generated, and this causes the steel to rip and tear along the relatively weak junctions of the non-metallic inclusions, and due to the accumulating pressure the steel is forced outward to form a blister.

It will be appreciated that rolled steel plate or tubes which contain an excess of non-metallic impurities, and rimmed steel, will be specially susceptible to the formation of hydrogen blisters.

The use of clean killed steel and the avoidance of rimmed steel for pressure vessels will go some way to prevent " blistering." Unfortunately hydrogen attack has other deleterious effects on steel, as evidenced by loss of ductility and hairline cracking, both on the surface and below the surface of the steel.

The problem of hydrogen attack has been studied and investigated by a number of authorities, and whilst there does not appear to be any method of protecting the steel which can be considered entirely effective, it has been demonstrated that if the positions at which attack may occur are known, modifications to processes and operations can be made to counteract hydrogen penetration.

" Weld Decay " of Austenitic Steel

In the chemical industry extensive use is made of chromium–nickel austenitic steel because of its superior corrosion-resisting properties. An additional advantage is that austenitic steel does not harden as the result of heating and cooling, and is in consequence a satisfactory material for fabrication and welding. In the early days of its application, however, it was found that austenitic stainless steel was liable to corrode very rapidly adjacent to and on each side of a weld. This was due to a modification in micro structure which took place when the steel was heated in the range 500° to 850° C. Thus austenitic steel which had been heated by welding was found to be impoverished of chromium in the vicinity of the weld, due to the precipitation of chromium carbides from solid solution at the grain boundaries. Corrosion attack readily took place at the grain boundaries and rapidly brought about intercrystalline disintegration of the steel.

The steel-makers overcame this difficulty by including a stabilizing element (titanium) in the steel, which prevents chromium carbide precipitation. Stabilized austenitic steel is essential for welding purposes. It is resistant to many corrosive conditions, including nitric, acetic, or phosphoric acids. It has been used with success in distillation plants for distilling crude phenols, where the conditions are specially corrosive to ordinary steel. For resistance to sulphuric acid solutions, however, a molybdenum-bearing austenitic steel is necessary.

Cast Iron

Ordinary cast irons are not as a rule used in engineering in positions where corrosive attack is likely to occur. Special cast irons have been

developed to resist corrosion. Nevertheless, cast iron offers a better resistance in certain corrosive environments than mild steel, for example, sea-valves and the water-boxes of condensers have been proved to give better service when made of cast iron. During the war it became necessary to substitute mild steel for cast-iron sea-valves, and also condenser water-boxes, because of their susceptibility to the effects of underwater explosions when made of cast iron. The mild-steel parts exposed to seawater, however, were not satisfactory from the point of view of corrosion. Improved service has, however, been obtained by the use of sheets of good-quality natural rubber bonded to steel condenser doors.

Austenitic cast irons have been developed which offer high resistance to wear, erosion, corrosion, and heat. Their resistance is, however, influenced considerably by conditions of temperature, concentration of corroding media, and effects of erosion. Tests have shown that the corrosion of ordinary cast iron is as much as ten times that of austenitic iron when exposed to the atmosphere. In many cases the resistance of austenitic cast iron to corrosion is comparable with that of brass and bronze. This corrosion-resisting cast iron has been used with success for such engineering parts as centrifugal-pump bodies, impellers, pistons, piston-rings, hydraulic rams, valve-chests, sewage plant, seawater pipeline, and various vessels and plant for the chemical and oil industries.

Figs 27 and 28 show examples of cavitation erosion of cast-iron propellers. This severe form of pitting usually occurs towards the tips of the propeller blades, and the wastage can be very rapid under suitable conditions. As shown in the photographs the erosion occurs on the back or suction side of the blade near the leading edge. It will be observed that the pitting has resulted in complete perforation of the blades, and on one blade (Fig 28) the blade tip has disappeared altogether.

The factors which influence cavitation erosion are propeller design, material, and working conditions. Research under all three heads is being carried out, since much remains to be learned in the study of cavitation problems. Cast-iron propellers are invariably fitted in single-screw ships, and this fact alone means that the ship's hull, sternframe, and rudder interfere with the water flow through the propeller.

Protection

Cathodic protection is based on the principle that the supply of a uniform electric current flowing into the metal from the electrolyte can prevent the anodic dissolution of the steel. The galvanic action of metals which are anodic to iron and steel provides an alternative method of " cathodic protection " frequently applied in practice. Iron and steel can be made cathodic either by being part of a current-producing cell or by having current applied from an external source and an inert anode such as carbon. In this way its corrosion rate can be reduced to a minimum. It is common practice to protect buried pipelines and steel structures in this way. In the former system, which might be called the " galvanic type," anodes of zinc, magnesium, or some other metal less noble than steel, are placed at strategic positions in the electrolyte surrounding the part to be protected, which then becomes cathodic. This system leads to a gradual dissolution of the

anode and at the same time to a build-up of precipitates on the surface of the cathodic areas.

In the latter system (of applied e.m.f.) it was recently stated at the Symposium on the Corrosion of Buried Metals held in December 1951 by the Iron & Steel Institute and the British Iron & Steel Research Association that, to ensure protection, a current of between 1 and 15 mA/sq. ft. of exposed surface was necessary. It was also pointed out that by maintaining the steel at a potential of 0·85 volts (silver chloride scale) full protection could be obtained.

The current required diminishes with time because the deposition of precipitates at the cathode tends to form a protective "crust" which reduces the current demand per square foot of surface. In seawater, magnesium and calcium compounds are precipitated, forming a white deposit which covers the surface of steel being protected.

At high current densities, of the order of 1 amp/sq. ft., it is possible to clean a steel surface by cathodic action. Rust scale and paint can be removed by the application of sufficient current, and experts on the subject consider it a wise precaution to limit the potential at the cathode to 0·9 volts (silver chloride scale) in order to prevent the removal, or partial removal, of protective paint.

Magnesium anodes, frequently used for pipeline protection, have a potential of about 1·5 volts. Except in experimental work very little experience has been obtained of cathodic protection of ships' hulls. A particular problem in ship protection is the disturbance caused by movement and turbulence, which makes it difficult to maintain a steady potential.

Zinc plates are commonly used on ships' hulls in the vicinity of non-ferrous parts, such as at the stern in way of a bronze propeller. This provides the galvanic type of cathodic protection, but suffers from the effects of decomposition of the zinc, which clogs the anode and tends to prevent the flow of current. Its potential, however, is only slightly above the upper limit of 0·9 volts recommended above as the safe limit for cathodic protection, and in consequence the use of zinc does not necessitate the same degree of control of hull potential as in the case of magnesium, which, due to its higher potential, requires careful adjustment to prevent damage to paint. With magnesium anodes fixed to the hull of a ship it would probably be found necessary, for efficient cathodic protection under all conditions, to incorporate a resistance control which can be operated from inside the ship for the purpose of adjusting the local potential of the hull adjacent to the anode.

Other methods of protective treatment of ferrous metals include oxidizing, phosphating processes, electroplating, galvanizing, metal spraying, painting, and vitreous enamelling.

Oxidizing and phosphating involve immersion of the steel in chemical solutions and converts the metal surface into a less corrodible form. Oxide coating can also be obtained by heating in a suitable environment. Oxidizing has a certain decorative value, but is very limited in its resistance to corrosion. Phosphating, perhaps better known as "Parkerizing," does not in itself afford protection, but produces a receptive, or absorbent skin, which is specially suitable for oiling, lacquering, or painting.

There are a number of processes of electro-plating. The deposited metal

may be zinc, tin, cadmium, nickel, chromium, or lead. Freedom from porosity is important, particularly in the case of coatings such as nickel and tin, which are cathodic to the base metal. Due to inherent porosity, nickel and chromium coatings do not provide good protection. Cadmium and zinc coatings afford some degree of protection in marine and industrial atmospheres. They are both, however, corrodible metals themselves, and this limits their protective value.

The corrosion resistance of tin is much superior of that of zinc and cadmium. It is, however, cathodic to the steel base metal, and is therefore unsuitable under atmospheric conditions. One of its main advantages is that its compounds are non-toxic, and it is therefore largely used in the food industry.

Galvanizing is a " hot dipping " process in which the steel is dipped into a bath of molten zinc after being pickled and fluxed. The process affords a high degree of protection, and is commonly used in ships for water-pipe systems, tanks, etc.

A sprayed metal coating adheres by mechanical locking rather than by fusion or bonding with the base metal. It provides some protection against mechanical damage as well as corrosion, and the latter function is considerably improved by painting, for which the sprayed surface is particularly suitable.

Painting, varnishing, and enamelling are the most widely used form of protection. Paints and varnishes consist of mixtures of pigments, drying oils, resins, thinners, and solvents.

Pigments exercise an inhibiting action on corrosion, and since paint films are not normally impervious to moisture, the presence of pigment in the undercoat is an important safeguard. The most effective pigments are iron oxide, red lead, zinc powder and zinc chromates, zinc oxide, and white lead.

Bituminous paints are commonly used on ships and structures exposed to seawater. They are generally reliable, especially when painted over a pigmented paint undercoat. One of the difficulties with bituminous paints is their liability to become soft due to heat, and to become brittle in cold weather. Where racking strains are involved, a degree of softness is an advantage in avoiding cracking, but durability and resistance to impingement attack is adversely affected.

The protection of ships' hulls against bacterial organisms calls for an anti-fouling paint containing toxic compounds. Among the most important of these are cuprous oxide and mercuric oxide. Certain organic compounds have also been used with varying degrees of success.

Blistering and flaking of paint are the main troubles experienced in ships' hulls. Experimental work has indicated that the former may be due to the accumulation of hydrogen gas evolved either by cathodic electrolysis or diffused from steel plates which have previously been pickled. Whatever the causes of paint deterioration may be, the fact remains that they differ in their efficiency both in adhesion and permeability. Anti-fouling paints are not always equally efficient in resisting both fouling and corrosion. Moreover, the effective life of anti-fouling compositions varies considerably with different paints. Some give good protection for periods up to one year, others are good only for a few months.

There are other miscellaneous methods of protecting steel against corrosion. Vitreous enamels, consisting mainly of borosilicate glasses, are frequently used for lining tanks and containers in food and chemical industries. Aluminium and lead coating, sherardizing, fescolizing, and several other general and proprietary processes are available and suitable in particular cases.

Conclusion

In this review of corrosion problems in engineering the author has surveyed the main factors involved, including the circumstances in which corrosion takes place and the characteristics of the different types of corrosion which too often confront engineers in a variety of industries. In recent years much attention has been given to the subject, and research and experimental work on a large scale has enabled a close study to be made of the mechanism of corrosive action and has led to considerable improvement in methods of protection, and thereby increased the useful life of metal structures and parts, with a consequent saving in the use of new materials.

Acknowledgments

The author desires to express his thanks to the Institute of Metals for the loan of the blocks for Figs 16 to 22 inclusive, which were originally used in a paper given by I. G. Slater, L. Kenworthy, and R. May to the Institute of Metals, and published in the *Journal of the Institute of Metals*, June 1950.

Discussion

Dr U. R. Evans: It gives me much pleasure to open the discussion on Dr Dorey's paper, which, coming from a distinguished and experienced engineer, puts the practical results of corrosion in a form likely to be acceptable to the engineers. Many of his practical examples of corrosion will be valuable to those who have to inspect structures for early signs of corrosion, telling them where to look and what to look for. Some disastrous breakdowns due to corrosion might not have occurred had the inspectors really known the symptoms and incidence of the disease.

With most of Dr Dorey's lecture, I am in entire agreement. I desire to direct attention to certain passages which, I feel, require some slight qualification. It must not, I hope, be concluded that, because my words expressing a certain amount of dissent occupy more time than those expressing agreement, I am in serious disaccord with the paper as a whole.

Dr Dorey states that "small quantities of impurities tend to initiate corrosion." That is sometimes true. Plates of pure iron and steel exposed on the roof at Cambridge quickly showed different behaviours. After a few days the steel was rusty, but the pure iron was still bright; a little later, however, both became rusty, and when after 228 days' exposure the plates were cleaned and weighed, the steel was found to have suffered slightly less corrosion than the pure iron, although the difference was very small. Four specimens of pure iron lost 1·156, 1·109, 1·159, and 1·143 g, average

1·142 g. Four steel specimens lost 1·057, 1·1187, 1·087, and 1·075 g, average 1·084 g. Very instructive facts emerge from Girard's comparison of cast iron and steel in salt water. On cast iron the graphite flakes apparently act as cathodes with the iron grains as anodes, and the solid corrosion product, formed close to, and within, the graphite network is retained, slowing down the corrosion; on steel under the same conditions the anodes and cathodes are large areas, respectively the parts inaccessible and accessible to oxygen, and the rust is precipitated out of physical contact, so that the steel plates diminish in weight, whilst the cast iron plates, after the early stages, gain weight. Thus cast iron sometimes resists better than steel, despite the larger quantity of non-metallic constituent—as is indeed stated by Dr Dorey.

The impurity in steel which does increase corrosion is sulphur, but this does not provide cathodes, but rather stimulates the anodic reaction, as brought out by the extensive work of Hoar. Sulphur, either in the metal as sulphide or in the atmosphere as sulphur dioxide, is dangerous, increasing both probability and conditional velocity. For practical men, the probability that attack will start is sometimes more important than the velocity with which it will proceed if once it has started. Mears' measurements in my laboratory show that sometimes probability may be increased by factors which depress velocity. Dr Dorey—despite (or perhaps because of) his relations with underwriters at Lloyds—has said nothing about probability. He has, however, pointed out the limitations of nickel plating owing to its porosity. Now on a microscopic area such as the area of iron exposed at a single pore in a nickel coat there is only a small risk of corrosion setting in; the combined risk that it may start somewhere when millions of pores are present is serious. This risk is likely to be increased by sulphur in the steel, or as sulphur oxides in the air. Hence sulphur is dangerous even when a " protective covering " is to be provided. The composition and surface state of steel which is to be nickel plated is most important. Dr Shome, who has carefully studied the porosity of nickel plating in my laboratory, finds that roughness (such as a scratch line) enormously increases the frequency of pores, and therefore the total area of iron exposed; it is the surface irregularity—not the internal stress—which is important, since the effect remains after annealing.

In Table I is shown a modified potential series of metals, and it is suggested that any material will be anodic to one standing below it in the table. The table is based upon the well known table of normal electrode potentials, which refers to film-free metals in normal solutions and which therefore has limited appeal to engineers, who are not concerned with film-free metals or with normal solutions. Thus Dr Dorey and others have modified the sequence, altering, for instance, the position of aluminium (a metal carrying a highly protective film) so that, in Dr Dorey's table, it stands below zinc instead of above it. Such a modified sequence certainly accords better with engineering experience than the series as found in the electrochemical text-books, but it has less precise meaning and is more likely to mislead. The frequent display of this " Practical Man's Potential Series " without the appropriate caveat fills me with misgiving. It should always be stated with the greatest possible emphasis that the order varies enormously according to the liquid wetting the metals, and the relative replenishment of oxygen

at the two surfaces. The case of aluminium and steel is being much discussed at the present time—by practical men for practical purposes; they are all agreed on one thing, namely, that the situation is extremely complicated—far more so than might be supposed from Dr Dorey's statement; sometimes aluminium is cathodic to steel—not anodic, as indicated in Table I. Similarly, zinc, which is anodic to steel in most cold waters, becomes cathodic (in some but not all waters) when the temperature approaches boiling point. A galvanized coat will often protect steel against cold water, even when the latter is exposed at sheared edges; this protection is rarely obtained in hot-water systems. On this subject the work of Gilbert is most important. Again porous tin coats will not protect steel against atmospheric attack, as Dr Dorey points out, since tin is cathodic to steel; in most fruit juices (bilberry juice is an exception) tin is anodic to steel, and hence canners can pack fruit in tin-plate containers. Numerous other examples could be given. Whatever justification may exist for the "Practical Man's Potential Series"—if accompanied by a suitable caveat—the table can be misleading and indeed dangerous if that caveat is omitted.

Dr Dorey reproduces the curves of the American investigators, Parr and Straub, regarding caustic cracking. It would have been fair to our American friends if he had published also the work of later American investigators, some of whom are critical of Parr and Straub; personally, I should have welcomed reference to British work, notably that of Weir of Glasgow. The sulphate-ratio method was accepted by the ASME in one of their early boiler codes, and omitted from a later edition; it is understood that it is to be reintroduced—without definite recommendation—into the next edition. About the time when the ratio was becoming to some extent discredited in America, the British BS 1170 appeared, tentatively recommending the sulphate-ratio method. There is no doubt that American railway engineers condemn it. The following is an extract from Bulletin 490, American Railway Engineering Association, November 1950:—

> "On the railroads it was found that embrittlement was occurring in boilers where high sulphate–hydroxide ratios were maintained, and no embrittlement was being experienced with feed water containing no sulphate and a very high sodium carbonate content. The sodium carbonate hydrolized into sodium hydroxide in excessive amounts at boiler temperature. . . ."
>
> "Due to the fact that the sulphate-hydroxide ratio maintained in steam boilers was found worthless as an inhibitor in railroad service . . . it is the opinion of your committee that the railroads should disregard the sodium sulphate–hydroxide ratio recommendations, as outlined in the ASME Boiler Code of 1940, which ratios are of questionable value, and increase operating difficulties in railroad steam boilers."

Nevertheless, if any boiler engineer is using the sulphate ratio method with success, and is avoiding cracking, I hesitate before advising him to alter his procedure. The rational way to avoid caustic cracking is to limit the $(OH)'$ content. Since, however, in any boiler system, the concentration of all ions must vary with the place of sampling and with the time (relative to the blow down), it may fairly be argued that the ratio OH'/SO_4'' is a criterion more independent of chance conditions of sampling than the ratio OH'/H_2O. If so, there is perhaps some argument in favour of the sulphate ratio method. However, in view of American railway experience

and Weir's statistical analysis of the quantitative data, it would seem that the method cannot be relied on. If the object is to prevent the $(OH)'$ concentration rising to dangerous proportions, surely the method of Purcell and Whirl deserves consideration, since this has a rational scientific basis. If the water is so controlled that, when the $(OH)'$ approaches a dangerous range, solid trisodium phosphate separates out, automatically preventing further increase in $(OH)'$, it would seem that a fair measure of safety can be achieved. The method is condemned on the grounds that it needs careful chemical control, but the sooner it is recognized that a qualified chemist is an absolute necessity in a power station, the sooner shall we overcome our difficulties. Whether the Purcell–Whirl method would serve for marine boilers, I do not know.

The nitrate method also deserves careful consideration. Weir considers it on technical and economic grounds the best treatment for low- and medium-pressure plant.

Dr Dorey : It affords me added satisfaction in having written the paper that Dr Evans should have come here as an expert to give his views. I am not an expert on corrosion ; but it is Dr Evans's special subject, and we should consider with great care all that he has had to say.

I am very interested in what he has said with regard to caustic cracking ; it is still with us, and we naturally welcome any further information which is of value in helping us on the road to curing the trouble. I cannot say more than that, except that there are cases which do occur, as Dr Evans has stated, and I think that the use of welding and less riveted work may get rid of the trouble very much better than any other treatment that is suggested.

Another matter that he has mentioned, that of the porosity of coatings, is also very important, particularly when it is not possible owing to economic pressure to apply coatings as thick as those used in the past. But even in the past one has always been somewhat suspicious of them in certain environments, and their success depends largely on the manner and care with which the coatings are deposited.

Some years ago we had considerable trouble with the breaking of piston rods of 8 inches diameter, fitted into double-acting oil engines. Some of the rods cracked after six or nine months of service, due to the fact that, the engines being double-acting, the only way in which the pistons could be cooled was by arranging the cooling water to pass up through the hollow piston rod. Accordingly, there was an internal pipe to take the water up, and the water returned on the outside of the tube, which brought it in contact with the bore of the rod ; the water being aerated in its progress through the piston and rod set up corrosion in the bore of the rod, and circumferential cracks occurred with great rapidity. The deposition of nickel was tried on the bore of the rod without success. It will, of course, be appreciated that it is very difficult to deposit nickel satisfactorily in the bore of long piston rods, and corrosion through pin-hole porosity is often found to be more rapid than is the case where larger areas are exposed.

Reference has been made to the protection of ships' propeller shafts by means of brass liners which are shrunk on to the shafts. It has been suggested that the liner might be replaced by " fescoling " the shaft with

nickel where it is exposed to seawater. So far this has not been accepted, and it is doubtful whether the deposited nickel would be free from porosity and so effectively protect the shaft from corrosion. There is also the possibility that corrosion might be active under the nickel, and consequently not be observed at a periodical inspection.

Stainless steel tubes have been tried in condensers. You will quite understand that the preparation and finish of the surface may have a considerable effect on the corrosion behaviour of the material, and while it is quite easy to polish the outside of a tube, it is quite a different matter to obtain a similar finish on the inside of the tube. The water flowing through a condenser is on the inside of the tube, and if there is only the slightest defect on the surface of even a stainless steel tube, corrosion can be very rapid. The same action takes place due to the roughness of the surfaces in the cases mentioned by Dr Evans.

I am glad Dr Evans has pointed out the limitations of Table 1. My statement that the metals grouped together are *relatively* safe to use in contact with each other is, of course, very much a generalization, and the Table can therefore be no more than a rough guide, and where corrosion problems are to be met a more precise knowledge of the metals and the conditions in which they are to be associated will be necessary.

I agree with Dr Evans regarding caustic cracking, particularly his reference to American railway engineers' experience. We do not yet know the fundamental cause of the type of cracking to state with any degree of certainty, except by experience, what protective methods to employ and then only for specified conditions. I am glad he has made reference to Weir's work, which is certainly a step in the right direction.

C. W. N. McGowan : I should like to add a few remarks to those of Dr Evans on the subject of cathodic protection. We have had a most interesting lecture from Dr Dorey, but he has dealt chiefly with dynamic subjects, such as reciprocating or revolving parts. I should like to deal with static subjects, namely, pipelines, and the application of cathodic protection to marine structures.

There are two methods of cathodic protection. One is to bury a number of anodes of a suitable metal close to the structure to be protected. The table of potentials shows the differences between bi-metals, such as iron and zinc or aluminium or magnesium, which are sufficient to cause the current to flow. It is usual to provide the buried magnesium anodes in connexion with pipelines by installing units weighing about 22 lb each at a distance of about 10 ft from the line, and to connect the pipeline by wire to a variable resistance which can be adjusted to limit the flow of current and so to increase the life of the anodes.

Secondly, there is the use of direct current, which involves the employment of a transformer and rectifier, the direct current being fed into a ground-bed made of scrap iron, from which the current passes into the surrounding soil, later to enter the structure at all exposed metallic spots, finally returning to the source by another cable, pipeline, or structure. The effect of the current in the soil is to dissolve the ground-bed and cause the structure to be protected.

Both methods suffer from the same great disadvantage, that variations

in soil resistance between the buried anode and the structure can be caused by changes in moisture content. As the result of heavy rain the soil resistance will be low and the current induced will be increased. The resulting tendency is not only to over-protect the pipeline, but to cause bubbles to exude from the surface and to push off or loosen the coating of bitumen or hot coal tar which has been applied initially to the pipeline.

Pipelines are coated by machine with hot coal tar, wrapped with Fibreglass strip, and coated again. Even so, it has been found most desirable to instal cathodic protection, especially where the ground changes in respect of ohmic resistance from low spots to high spots, thereby inducing current to flow between the pipe and the anode, producing varying degrees of corrosion throughout the length of the pipe.

In a tank farm where the tanks have been painted with aluminium paint in the normal way, cathodic protection is provided in addition, particularly where the tanks are founded on a bitumen mat.

In the case of two 12-inch submarine lines feeding oil into tankers about a mile off shore, these were just bitumen-coated steel pipes. More recently, after about three years of service, it was found that cathodic protection would work satisfactorily, and the results show that the pipes are now adequately protected.

The Kuwait oil jetty, the largest in the world, was planned at a time when development was so rapid that it had to go ahead, although there was very little information to be found with regard to the effects of the Persian Gulf seawater. It has about 4000 steel piles ranging in lengths up to 100 ft. The reason why steel was adopted for such a structure was that sources of aggregate for concrete were very sparse; that rather ruled out the use of reinforced concrete, unless the reinforced concrete were brought from some distance, in which case the costs would probably have been exorbitant. The use of timber was ruled out because of the great length of the piles required, for the depth of water at the seaward end is no less than 50 ft at low water. In the interests of speed and ease of construction in difficult conditions, steel was resorted to. But obviously the problem of corrosion is a very formidable one. Initial protection for the piles was provided by coal tar enamel applied by pouring. The piles were fitted at each end into grooved wheels which rolled on parallel rails, and as the piles were gradually turned over, the hot enamel flowed freely down the faces; it was found possible in practice to obtain a reasonably even thickness of protection. The scheme worked very well indeed. But, as was inevitable, in the transshipment of the piles from the yard where they were coated to the craft carrying the pile driver, and in the driving, a certain amount of damage was done to the pile surfaces.

Thus there is a very big corrosion problem to be tackled here, and cathodic protection was regarded as being the most suitable form. Magnesium anodes, each 200 lb in weight and about 2 ft in diameter, are placed on the sea bed in the immediate neighbourhood of the structure, and connected by a wire suspended by a spool insulator immediately below the deck. There is a further wire to the junction box for the insertion of a resistance control and for earthing of the structure.

After installation it was found that potentials could be maintained well

above the recognized minimum figure of 0·85 V; and in connexion with the approach pier the figures were from 0·99 to 1·04 V.

Cathodic protection was brought into operation in December 1949, at which time about twelve similar test sets of magnesium anodes were installed. These were lifted in April 1950. Initially they weighed 215 lb, and after an immersion period of 2900 hr the loss of weight was about 61 lb. Calculations showed that the output from each of the specimens was 11,700 amp-hr, or about 3 amps/hr. On this basis it was determined that the anode efficiency of 24 per cent would produce a life in the anode installation of this structure of about two years, and that is working out to be reasonably correct.

Altogether about 60,000 lb of magnesium was installed in this way. But in order to provide a more permanent scheme and to eliminate the continual consumption of magnesium, it was decided in April 1950 to go in for rectified current, and at the present moment that installation is just about complete. We think that with rectified current from our power station near the jetty we shall have a means of protecting the jetty about which we can feel confident, provided the results we have obtained from experiments so far are borne out by future findings.

Dr Dorey: Before I went to Kuwait in 1949 I heard—though it may not have been a correct statement—that the pier was corroding away as fast as they could put it up, and those responsible were worried as to what they could do about it. The cathodic protection scheme was not then in being, but I saw the pier being erected. I saw the coatings that were being applied to the various parts of the structure, and I felt that there were opportunities of damaging the coatings before the components were finally in place. Any cracking of the coatings, of course, defeats the purpose for which they are applied, and indeed, it makes things worse.

The Kuwait Oil Company, however, have provided a fine illustration of what can be done by cathodic protection, and it will be very interesting to study the rectified current system when complete details and experience are available.

K. A. Spencer: In the oil industry we are faced particularly with the problem of seawater cooling at many new refineries now being engineered, and the effect of seawater on cast iron at varying temperatures is of importance. In one communication I have seen quoted a graphitization rate of 0·1 inch per annum on a 44-inch cast iron main, at temperatures of the order of 70° to 90° F, of 0·1 inch per annum. We are now faced with the probability of having cooling effluent seawater in cast iron lines at 90° to 110° F.

There is the problem of what to do about providing a coating. It is necessary to apply a coating, and if it is necessary, what type of coating should be used? If graphitization takes place, does it go on consistently or slow up, and does it pit or become uniform? I hope to be able to obtain the views of somebody here who may have had some experience on this matter. For a period I have been trying to get solid data, but so far have not obtained very much.

In Dr Dorey's paper, under the heading "Protection," there is reference to a statement made at the Corrosion Symposium in 1951 that, by maintaining steel at a potential of 0·85 V to its electrolyte, full protection could

be obtained. It is a small point, but it should be noted that in this particular reference the half-cell used for potential measurement was that of copper/copper sulphate and not silver/silver chloride as stated in the paper under discussion.

DR DOREY : I cannot give Mr Spencer very much advice; I think it is a question of trial and error. There are several things that he can try; for instance, he might try spraying a chlorinated-rubber base paint on to the pipes, or using a cementiferous paint. But I think that once cast iron begins to get soft, it will continue to get soft. We know how condenser doors have behaved in the past. I can assure Mr Spencer that he must find an appropriate coating, but I think that one would want to know a little more of what is going through the pipe in order to be able to say which is likely to be the most effective coating. I suggest Mr Spencer consults Girard's work referred to by Dr Evans.

DR A. L. DOWN : Dr Dorey's paper is essentially of a practical nature, which is always so refreshing to those who have to face these problems, and I should like to make some remarks on the section dealing with corrosion in oil process plants. Dr Dorey has referred to corrosion caused by hydrolysable chlorides, particularly magnesium chloride, in topping units. In Trinidad experience has shown that a simple way of overcoming this corrosion is by the introduction of a comparatively small amount of caustic soda solution to the crude oil entering the unit. This results in all the chlorides present being converted to sodium chloride. The water present in the crude is completely flashed off, or reduced to less than 0·1 per cent, in the pre-flash tower and, under these conditions, the sodium chloride remains in suspension in the oil passing through the heater tubes, with little or no deposition, and leaves the plant in the fuel oil, again not causing any marked fouling of the fuel-crude heat exchanger tubes. The soda injection is controlled by checking the aqueous condensate in the overhead receiver for chloride content. A maximum of ten parts per million of chloride is specified, and the operators normally have little difficulty in adjusting the figures to zero.

Reference is also made by Dr Dorey to the use of alloys, and the point is made that in some cases cast iron is better than an alloy steel. In general, Trinidad experience has been that 4 to 6 per cent chrome is not a very satisfactory material for bubble deck assemblies. On the other hand, 11 to 13 per cent chrome alloy is particularly useful for the higher temperature corrosive conditions such as occur in the main fractionating columns of thermal cracking units, where considerable amounts of sulphur compounds occur in the product. When using cast iron in such locations the products of corrosion completely foul the trays, and after a year, the columns are filthy dirty. On the other hand, when using 11 to 13 per cent chrome trays the columns are as clean after a year's operation as at the beginning, and the corrosion is virtually negligible. However, it is particularly important not to use 11 to 13 per cent chrome trays under conditions in which water, if present, could exist in the liquid phase together with hydrogen sulphide and sulphur dioxide, as the life of trays would then be liable to be as short as one year.

J. R. THOMSON : I should be grateful of Dr Dorey's opinion concerning the practice carried out in a foreign oil refinery of keeping the exit temperature of salt water from the cooling jackets of gas compressors below 130° F, on the assumption that higher temperature would accelerate corrosion in the steel piping. No serious corrosion was encountered.

DR DOREY : It is known that temperature has an effect, but much depends on the conditions, and with salt water cooling trouble can be experienced at 60° F. Experience indicates that seawater is not good for use in the cooling jackets of compressors and oil engine cylinders.

So far as steel piping is concerned the composition of the steel and the temperature and velocity of the seawater are all factors which influence rate of corrosion. The aerated condition of the water does not improve matters, particularly if there is any possibility of impingement.

THE CHAIRMAN : On the marketing side of the petroleum industry one of the greatest troubles experienced was the internal corrosion of white oil lines which were cleared with seawater. Normally these lines start to corrode internally after about six years. But their life can be prolonged by turning the pipes so as to allow them to wear out on each quarter in turn. We have found also that by spinning a concrete lining in a pipe we have managed to prolong its life considerably; and that can be done also with secondhand pipes.

Again, we have achieved considerable success by putting a cement lining in a pipe *in situ* by the Tate process, which was developed originally for water lines; and in view of the shortage of steel at the present time, we have repaired lines which normally we should have replaced completely. We have done that in Australia, New Zealand, North Africa, Italy, and French West Africa. Our experience of it now extends over four or five years, and it has proved very successful.

A matter which Dr Dorey did not mention in his paper is that of inhibiting corrosion in product pipelines. In the U.S. they have various inhibiting processes, using sodium nitrite, which have proved very successful. An inhibiting system was used on the United Kingdom pipeline grid during the war, and it resulted in keeping the pipelines very clean.

On the question of under-sea pipelines and structures I think there are two schools of thought. One of them is to protect the pipelines as completely as possible. In the old days, before anybody had thought of cathodic protection, it was found that any damaged part of a line corroded very much more quickly than any other part; and there were really more leaks when there was good protection than when there was no protection at all. The Americans put down an under-sea line at Accra in 1943; it was an 8-inch line which ran for a mile under the sea, and it had no protection. That line, on the outside, is still going strong, but on the inside it is not so good, because there are white oils going through it. There is general corrosion all over the line, but no heavy local corrosion.

I think that insulating flanges on either side of river crossings are of assistance in preventing currents in the lines, giving rise to electrical corrosion at damaged portions.

In conclusion, I should like to put one question to Dr Dorey. He showed

a photograph of a propeller with the words " Cape Town " painted on it, and that part of the propeller was the only part which had not corroded. I think we are familiar with similar cases; you may go into an old oil tank, maybe fifty years old, and you will see the makers' original paint marks on the inside. I should like to ask whether, if the whole of the inside of such a tank, or the whole of the propeller which Dr Dorey illustrated, had been painted with that particular paint, corrosion would have been prevented.

DR DOREY : That depends on the paint, on whether it will wear uniformly or is applied uniformly. It is also a question of the local environment. The manufacturer perhaps thinks that the painting of his name provides a good advertisement, and is therefore very careful about the way in which the paint is applied for that purpose.

I am very glad to have had the opportunity to come here. The paper is a practical one, and it would be interesting to obtain some more practical information. Dr Evans devotes his life's work to this subject, but he does not always come into contact with its effects and consequences as do many of us who work in the industrial field. The more we can draw his attention to the cases that come to our notice, the better is he enabled to give us his advice on how to overcome our troubles, whilst at the same time he may hear something he has not heard before which will help him in his study of our difficulties. I do hope you will not be slow in bringing interesting cases to our notice.

THE CHAIRMAN : On behalf of us all I should like to thank Dr Dorey once more for his most interesting and excellent paper and for having spared the time to come here to-night. The discussion has been of very high quality, and I would like to thank Dr Evans for having given us such interesting comments on the paper.

I know that you will all welcome the opportunity to express your thanks.

(The vote of thanks was heartily accorded.)

WRITTEN DISCUSSION

S. E. BOWREY : Dr Dorey has mentioned the use of sodium nitrite for arresting salt water corrosion of machinery. A few remarks on the method may be of interest.

The use of sodium nitrite in turbine lubrication systems was developed * in the Royal Navy to overcome the very severe corrosion found in the turbine bearings and gearing of certain ships during and immediately after the war.

Entry of salt water into an oil circulation system may arise from a variety of causes, some due to action damage, others purely accidental. It is now part of the daily routine in H.M. ships to test the water from the oil separator for salt, and the use of sodium nitrite is ordered in all cases where significant salinity is detected.

When sodium nitrite solution is added to the oil in circulation, it should be mechanically dispersed but not emulsified. The droplets can then

* British Patent Application No. 29221/48.

coalesce with the salt water retained in the corrosion pits, after which anodic inhibition takes place and corrosion ceases. The solution is later removed by centrifuging and normal operation resumed. Treatment is usually completed within two or three days, but takes longer where corrosion is severe.

In using nitrite solution it is obviously necessary to avoid interference with lubrication, but it can be claimed that a completely safe procedure has been established. Sodium nitrite treatment has been applied in some ten or twenty ships, including several merchant ships, and has been uniformly successful.

The nitrite paste mentioned by Dr Dorey affords a means of obtaining similar results after corroded machinery has been dismantled. It might be supposed that the normal cleaning up during a refit would put an end to active corrosion, but such is emphatically not the case. Instances are on record of ships' machinery which has been overhauled and thoroughly cleaned, but has nevertheless corroded as badly as ever within a few weeks or months. Even when salt-corroded bearings have been machined and appear perfect there is no certainty that the deeper centres of inter-crystalline attack have been eliminated. "Poulticing" the affected surfaces for a few days with nitrite paste arrests the corrosion and, provided there is no further contamination with salt water, prevents its recurrence.

Dr Dorey wrote in reply: I am indebted to Mr Bowrey for the detailed information he has given of the application of sodium nitrite in turbine lubrication. Sodium nitrite is also used as an inhibitor in fresh water, particularly where used in hydraulic experimental equipment, *e.g.*, large tanks, pipes, cavitation tunnels, etc.

Julian S. Tritton: Caustic cracking or embrittlement is serious in that it is not often that evidence of its presence is apparent before the cracking has reached an advanced stage.

The author mentions that it is caused by concentrations of caustic soda in lap joints due to minute leakages through the caulked joint or via rivet heads. If leakage could be prevented no caustic cracking would be possible.

Testing of the caulking of joints inside the boiler or pressure vessel is hardly feasible and, in any case, breathing of the plates may cause some leakage. Does the author consider that seal welding of inside seams would improve matters? It is realized that seal welding (without stress relieving) will result perhaps in more corrosion than local hardening from caulking, but it would at least be visible on examination.

Excessive pressure when closing the rivets sometimes accelerates the cracking, as this always occurs at highly stressed portions of the plate. To get leak-free rivets correct heating and descaling is required, the closing being done by a steady pressure maintained for a predetermined time.

From the wide experience of the author, I should be interested to know, assuming the plating to be good, whether he could say:—

(*a*) what is the minimum riveting pressure per sq. in. of rivet body that will give a tight rivet;

(*b*) what is the minimum length of time that this pressure must be maintained?

DR DOREY wrote in reply : I see no objection to seal welding riveted seams of boilers on the water side in order to prevent seepage into the interstices of the seam. It would be better still to dispense entirely with riveted seams and adopt all-welded boilers. The drums of water tube boilers are nowadays usually completely welded, and an increasing amount of welding is being used in the construction of cylindrical multitubular boilers (Scotch boilers).

In regard to riveting pressure, experience has shown that the most suitable riveting pressure was of the order of 60 ton/sq. in. of riveted shank area. The length of time during which the pressure should be applied will, of course, vary with the size of rivet, the governing factor being the need for closing the rivet whilst it is still hot. In the process of closing the rivets care must be taken to see that the dies do not press into and punish unduly the adjacent plating.

THE INSTITUTE OF PETROLEUM

A MEETING of the Institute of Petroleum was held at 26 Portland Place, London, W.1, on 14 May 1952, Mr H. S. Gibson, C.B.E., being in the chair.

THE CHAIRMAN said he thought it almost presumption on his part to introduce Dr G. M. Lees because he had so long been a member of the Institute and because he was sure they would all be most interested in the paper he was to present on the distribution of the oil reserves in the world.

He was very glad that his first occasion of taking the chair should be that one, for he was sure that Dr Lees' lecture would not be the usual rather solid geological discussion. Whenever Dr Lees discussed a subject he looked at it from a very different angle and introduced thoughts which caused other people to think also.

The following paper was then presented by Dr Lees.

THE DISTRIBUTION OF THE OIL RESERVES OF THE WORLD

By G. M. LEES, F.R.S. (Fellow) and D. C. ION

INTRODUCTION

THE authors have been asked to discuss in general terms the distribution of the known oil reserves throughout the world and to give an estimate of the trend and extent of future discovery. The world is now consuming its accumulated store of liquid energy at the rate of 600 million tons per year, and demand is increasing inexorably as our civilization becomes even more mechanized. The average yearly increase over the past twenty years has been nearly 5 per cent, and if this rate is maintained the world will require 1400 million tons per year in twenty years' time.

The proved reserves of the world as at present estimated represent about twenty-four years of supply at the current production rate; no allowance is made in this figure for future discovery, as naturally only general trends and not facts are involved. For many years past discovery has approximately kept pace with demand, and as so many past predictions of coming shortages of supply have been disproved by events, there is an understandable tendency to discount such forecasts. Nevertheless, experience is cumulative, and there is now a formidable volume of new knowledge on which to base a forecast.

Any estimate of the total recoverable oil reserves of the world is further complicated by the formidable economic unknowns of the future. Small accumulations of oil are common throughout most areas of sedimentary rock cover, but major accumulations are exceptional. A small field,

yielding say 100,000 tons per year, may be profitably developed in an industrial area, but in a tropical forest hundreds of miles from markets or from seaboard the same field is valueless at the present time. Should this oil in the latter case be included in an estimate of the working reserves or not ?

The estimates of proved reserves are based on recovery factors which themselves depend on a combination of ever-improving technique and on economics. Secondary methods, such as water drive, have increased recovery of oil from its reservoir from about 30 to 50 or even 75 per cent or more in very favourable cases, but the length of the " stripping " life of an oil well depends on the relation of costs to the value of the product. In some places even 100 per cent extraction can be achieved by mining depleted oil sands, as at Wietze in Germany, where crude oil has an artificially high value due to protection.

An interesting example of the interaction of economics on reserves is afforded by the coal position in Britain. In 1905 a commission reported confidently that Britain had at least 500 years of supply and perhaps very much more, whereas the recent inquiry has suggested only about 200 years of supply. The difference is largely because of a change in the economic structure of the industry. In 1904 it was profitable to mine seams of as small a thickness as 18 inches, but now a 3-ft seam is generally the economic limit. The great reduction in our workable reserves is mostly on this account and not because of any physical estimating error on the part of the 1905 investigators; perhaps an inquiry in fifty years' time may revert to a figure closer to that of 1904 as a result of an improvement in the technique of mining thin seams or of some other method such as underground gasification or of some change in the relative values of labour and fuel.

But before oil reserves can be firmly estimated they must be found, and in general the controlling factor is the intensity of search, and again this is determined by economics.

The intensive oil search throughout the U.S.A. and its massive success has indicated that other countries having comparable sedimentary rocks should be able to achieve a similar result given a similar intensity of effort. Can it be assumed that the economic conditions which nurtured the American effort will be possible in other areas, and therefore can the U.S. experience be used as a yardstick to measure the ultimate reserves elsewhere ?

In analysing the possible distribution of the future oil reserves of the world we have become so conscious of the inter-connexion of economics and geographical factors that for an estimate to have any practical value it must be related to the time element. For example, Antarctica may theoretically contain immense oil reserves; practically, they must await development until we have emerged farther from the effects of our recent ice age into the " sunlit uplands " of the distant future. Instead of attempting an estimate of the total reserves of the world, the possible trend of events during the coming twenty years have been studied. The world demand ahead has been projected at a rate based on past experience and an attempt made to predict the tempo of new discovery during that time taking all factors into account, not only the possibility of oil occurrence but also the physical effort required to discover and produce it. In 1972 the world demand may be at the rate of 1400 million tons per year, compared with the present 600 million ton rate, and the problem is to estimate

whether the proved reserves then will be on a scale sufficient to meet this massive requirement.

The Proved Reserves

The proved reserves of the world, as far as they are known and published, are distributed as follows, and the percentage change between 1938 and 1951 is significant in showing how North America and the Middle East have changed places in this interval :—

	1951, million tons.	Distribution by percentages.	
		1951.	1938.
North America . .	4,520	31	47
South America . .	1,620	11	12
Middle East . . .	6,900	48	16
East Indies . . .	240	2	5
Russia . . .	1,000	7	16
Others . . .	170	1	4
	14,450	100	100

The distribution of the proved reserves in the world is extremely uneven; North America and the Middle East contain 79 per cent of the world's total, South America 11 per cent and the remaining continents only 10 per cent; if the U.S.S.R. and East Indies are excluded, only 1 per cent is distributed among all other countries in Europe, Africa, Asia, and Australasia. Intensive exploration in many countries in this last class during recent years has had many failures, but in some cases it has proved oilfields which are important to the national economies, and yet the total proved reserves are estimated at only 170 million tons, distributed among the following :—

Roumania
Austria
Hungary
Germany
Poland
Czechoslovakia
Jugoslavia
France
Italy
U.K.
French North Africa
India
Pakistan
Burma
Japan
China
New Zealand
Albania
Holland

The accuracy of these estimates of reserves is not great, but nevertheless they are probably of the right order of size and relatively correct. The American oil industry has set a high standard of broad-minded policy to the rest of the world in the admirable yearly stocktaking of the API committee. New discoveries made during the year and additions to and revision of older fields are assessed, and the balance struck between production during the year and new discovery. These estimates are, of course, somewhat conservative, as there is usually a time lag between a new discovery

and the appreciation of its total reserves. Secondary recovery is not credited as applicable until it has been actually proved in any particular field, and so forth.

Compared with the U.S. estimates of proved reserves, those of most other countries are less accurate, and, in some cases, notably the U.S.S.R., no reliable data is available from which independent estimates may be made. In the absence of the basic facts the rate of production gives some guidance to the total reserves in that most fields of settled production yield their oil at a rate of between 5 and 10 per cent of the reserves, depending on the age of the field and the reservoir characteristics.

The reserves of the Middle East as published also cannot be regarded as exact, owing to the fact that no one individual has had access to all the details. Also by the nature of the oilfield characteristics, it is difficult to assess the total recoverable reserves at an early stage in the production life of the fields. The Persian fields produce from a fractured limestone of relatively low normal porosity, and it is notoriously difficult to estimate reserves until the reservoir behaviour is known consequent on a substantial production. The giant oilfield of Kirkuk, 60 miles in length, has a much more porous reservoir limestone, but adequate fissuring is the cause of the freedom of fluid connexion throughout the field. The Arabian and Qatar fields produce from limestones of high porosity, but, compared to Kirkuk, of lesser thickness and with fracturing a lesser factor. Kuwait, on the other hand, is a sandstone field with thick sandstone members of unusually high porosity and permeability, but in this case an estimate of reserves depends largely on whether or not a natural water drive will develop or, if not, whether secondary recovery is applicable, neither factor being known at this early stage in the productive life of the field. All things considered, therefore, it is probable that the published estimates of the Middle East reserves err on the low side, perhaps by 30 per cent or even more, but its dominant position in the oil world is so assured that any upward revision can only make its relative importance still more dominant.

As exploration throughout the world progresses it becomes even more clear that small oilfields are the rule and major or giant fields the exception. In the U.S.A. the distribution of proved reserves by States again illustrates very uneven oil richness, Texas having 52 per cent, California 13 per cent, Louisiana 8 per cent, Oklahoma 5 per cent, and all other States 22 per cent. Differently analysed, some 151 large oilfields out of a total of over 4000 fields contain 58·1 per cent of the U.S.A. reserves, and are contributing 47·5 per cent of current production.

The production rate from existing fields is governed by a variety of factors, partly technical, partly economic. It is :—

1951 *Production as Percentage of Published Proven Reserves*

	Per cent
North America	7·0
South America	6·0
Middle East	1·4
East Indies	5·4
Russia	4·2
Others	6·5
World average	4·0

The Total Oil Resources of the World

In the introduction is stated the reluctance to make an estimate of the total oil reserves of the world, that is, the present proved reserves plus new discovery to the end of time. But notwithstanding this reluctance, a partial analysis of the problem and some general indication of the order of magnitude cannot be avoided.

The first difficulty, as mentioned before, is to decide what should be included in a global estimate of oil reserves. Oil can be produced at a certain cost from coal and from oil shale, but these solid fuels come into a different category, and can reasonably be excluded from our inquiry, except to remark that the magnitude of the world's reserves of solid fuels exceeds by many times that of crude oil.

It is less easy to decide whether natural gas and/or heavy oil and tar should be included. Most oil-bearing areas contain comparable amounts in thermal value of gas and oil, and in industrialized countries their uses as fuel are to some extent interchangeable. In less developed countries where there is no normal market, gas is at present conserved as far as possible, but at a higher price level it could be converted into liquid oil, or could be transported in pressure vessels or in Dewar tanks. Immense potential reserves also exist in the form of heavy oil or tar, particularly in three great deposits, the Athabasca tar sands of Alberta in Canada, the tar sands of Eastern Venezuela, principally in the southern part of the State of Guarico, and the tar area of western Iraq. The Athabasca tar deposit has been variously credited with reserves of 15 to 35 thousand million tons, and those of Venezuela and Iraq may approach comparable magnitude. At the present time none of these deposits is being commercially developed, but undoubtedly they represent an important reserve for the future.

The geographical factor is a further difficulty in reconciling theoretical with realizable reserves. Immense areas of tropical forest in many countries are at present very lightly explored, in most cases because remoteness and operating difficulties so adversely affect the economics of possible development. Thus, to examine an extreme case, a large area of Ecuador, east of the Andes, was recently explored by drilling at very heavy cost with negative results, and the project was abandoned. The geographical and economic handicaps to profitable development are so great that only fields of major size are of immediate value, but if an area of the same geological character were in the U.S., perhaps one hundred times the number of wildcats would have been drilled. Many small oilfields might have been found and even some major fields. Possible oil reserves in this area of Ecuador have certainly not been eliminated by the few wells drilled, but the difficulty and expense of discovery are such that it will be many years before a renewed attempt is made. If the possible oil reserves of such a remote and difficult area are included in a global estimate of total reserves, the qualification must be stressed that many years, perhaps many decades, will elapse before they can be realized. An improvement in the price structure of crude relative to development costs would accelerate the process and vice versa.

The U.S.A. is the only major country in the world which has been intensively explored, and it would be reasonable to expect that, with such

a great cumulative experience, it would be possible to estimate its total reserves with some degree of accuracy and that this experience might be used for guidance in assessing the potentialities of less known countries. But it is not so. Expert opinion on the remaining reserves of the U.S.A. has swung from optimism to pessimism and back so many times that the authors' own conclusions cannot be expected to carry much conviction although, undeterred, they will be stated.

The most recent report on the future of American oil is by the McCollum Committee to the National Petroleum Council (January 1952), which states that : " the United States and the world can count upon increasing supplies of oil and gas not only for the next few years but for the foreseeable future. . . ."

At the recent AAPG Meeting in Los Angeles the general tone is reported to have been strongly optimistic, with the recently discovered Spraberry Trend of West Texas being likened to the great East Texas field and used as an example of the bonanzas which the industry can produce when needed.* On the other hand, the U.S. Bureau of Mines has for the last few years been advocating the subsidizing of a synthetic liquid petroleum industry in case domestic crude petroleum cannot fill the U.S. demand for petroleum in the not too distant future. The Geological Society of America also were not quite so optimistic in 1951 as the N.P.C. Committee and as Eugene Ayres of Gulf Oil stated the case (*Petroleum Processing*, Jan. 1952) : " The U.S. rate of importation is likely to rise moderately until 1960 . . . to rise sharply between 1960 and 1970." However, there is general optimism in the oil industry in the U.S.A.

The McCollum Committee dismissed estimates of ultimate reserves, saying that they have always been wrong and implying that they will always be so and that they are more dangerous than useful. While admitting the statement the implication is disputed. The amount of oil in the ground is a finite quantity and is not being replenished importantly. The great U.S.A. has developed a capacity for finding and expending a formidable volume of oil year by year, yet the total of proved reserves has increased, showing that discovery can more than make good production. But has this modern widow's cruse no flaws ?

The discovery history of the oilfields of the U.S.A. shows clearly that the effort involved at the present day to find a given quantity of oil is much more than what it was some years ago. The spectacular discovery phase which yielded the Los Angeles Basin fields, the Seminole and Oklahoma boom period, and the great West Texas peak period have had no counterpart for many years. The average size of discovery, notwithstanding rare exceptions, is much less now than it was twenty-five years ago, and yet in this interval all the tools of exploration have been enormously improved ; the capacity of deep drilling has made 20,000-ft wells possible, and the cumulative experience has opened innumerable geological windows allowing a vision into the deep unknown.

A detailed criticism of the McCollum report cannot be attempted in this paper, but a study of the position has led to very different conclusions.

* Some sceptics have described the Spraberry as the biggest uncommercial oil accumulation known.

There must undoubtedly be a formidable volume of oil still to be found in some parts of the U.S., but in others there is not much expectation of new discovery. In the great Mid-Continent region small fields are still being found, but the intensity of past search is such that there is relatively little scope for major discovery. Over much of this territory the crystalline basement lies at depths of under 10,000 ft, so the improvement in deep-drilling technique is not a factor. The State of Oklahoma has probably passed its peak of production, and California has little expectation of its present production rate being sustained for more than a few years. Texas is, of course, the greatest oil state, but although it offers most liberal hope for new discovery it is unlikely that as much remains to be found as has already been revealed. The Rocky Mountain states are at present having one of their many boom periods, and exploration has increased to a greater tempo than for many years past. The Williston basin discoveries may be of great importance, but will probably not exceed the size required to maintain the forward reserves position.

In many discussions on the total oil reserves of the U.S.A. the value of the continental shelf has been stretched, it is believed, far beyond its elastic limit. The discovery of oilfields in the Gulf of Mexico as much as 30 miles out to sea is an outstanding technical achievement, and the indication is that this area of buried salt domes may extend far seawards of the present proved limit. The value of this zone in the Gulf will probably be comparable to the adjacent coastal zone of Louisiana and Texas, of which it is a direct continuation both physically and geologically. Its value is on this account and not in any way because it is a continental shelf, and when other sectors of the shelf are assessed, this fact must be emphasized. For example, the oil prospects of the New England littoral are, for all practical purposes, nil, and so the prospects of the adjacent shelf are nil plus a small fraction to allow for some remote possibilities in Mesozoic and Tertiary sedimentary rocks not now remaining on land. All in all, the extra oil which will be won from the continental shelf zone of the U.S.A. is not likely to be on a scale to extend the total reserves importantly.

Various estimates of the total reserves of the U.S.A. have been made, but they differ widely, depending largely on the degree of optimism involved. Wallace Pratt estimated 100,000 million brl in 1942 for the total ultimate production, leaving, in 1952, 57,000 million brl remaining, of which 32,000 million brl are already discovered and classified as proved. Wallace Pratt's figure implies that the U.S. has only a total of about twenty-five years of supply at the present rate of consumption or a lesser duration if the total demand continues to increase.

It is clearly impossible to reconcile this estimate with the statement in the McCollum report (pp. 55 *et seq*) that " the prospective area (2,400,000 square miles) in which the industry thinks oil and gas may be discovered is about one hundred times as great as the areas of all the oil and gas fields discovered in the U.S.A. during the past 92 years of exploration." The implication is that the remaining areas not yet fully explored have an equal oil richness to those already proved, but although the qualification is made that the geological assessment may vary from district to district, the general impression is conveyed that there is much more oil awaiting discovery than has been found in the past.

Independent study of the problem has led to conclusions more in line with those of Wallace Pratt, but the authors are very conscious of the formidable uncertainties involved in any such speculative estimating, particularly as the shape of things to come in many other aspects is equally unpredictable. If conditions for the next twenty years continue in line with present trends, it is anticipated that the U.S.A. will have passed its production peak. Although discoveries will still be forthcoming, they will fall far short of what will be required to offset the advanced decline of the old fields. Demand will have to be supplemented by a combination of imports and oil from shale and coal, although perhaps a tight supply position will reduce the demand considerably by more economical use.

The importance of a study of the U.S.A. in any analysis of the possibilities elsewhere in the world is that the U.S.A. is the only major area which has been explored with such intensity. The experience has demonstrated that most sedimentary areas contain oil accumulations and that, if the search is intensive enough, they can be found; but a further facet of the experience is that small fields are the rule and major fields the exception.

The discovery performance has been analysed by Wallace Pratt, Stebinger, Weeks, and others to arrive at some relationship between cubic mileage of sediments and their oil content or, neglecting the third dimension, the oil reserves per square mile of sediments. The average for the whole sedimentary areas of the U.S.A. for total reserves, making generous allowance for future discovery, is likely to be of the order of 10,000 tons per square mile, but individual basins of exceptional richness such as those of California may yield up to 160,000 tons per square mile.

The extent of the sedimentary areas in the world as a whole are known within reasonable limits, and we have estimated those which satisfy certain conditions as potentially petroliferous as follows :—

	sq. miles
North America	2,768,000
South America	1,360,000
Middle East	1,343,000
East Indies	281,000
Russia	3,000,000
Others	1,364,000
Total :	10,116,000

If the U.S.A. experience can legitimately be used as a yardstick and the factor of 10,000 tons per square mile applied to 10 million square miles, the simple sum gives an answer to 100,000 million tons. But for reasons already stated it is not felt that such an estimate is realistic for the foreseeable future, even if ultimately acceptable. There may possibly be that amount of oil in the ground, but discovery and development in many remote areas will be so slow and incomplete that it would be quite unreal to apply the U.S.A. experience indiscriminately. The intensity of the search in the U.S.A. is the result of a combination of factors. The high degree of industrial development and the build-up through the years of the ancillary services and equipment supply for oil drilling make access to wildcat areas relatively inexpensive and assure quick development of a new discovery; the wildcatting principle is of enormous importance, and many fields have been found either by chance drilling or by profiting, both

geologically and geophysically, by the data from dry holes; furthermore, the security of reward to private enterprise encourages the speculative effort essential for success. Can one anticipate a time when the headwaters of the Amazon, the tropical swamps of Papua, or the perma-frost areas of Siberia will offer all these conditions in equally favourable conjunction?

Other unknown factors already mentioned are the effect of economics on recovery efficiency of oil sands, the possible use of the great tar sand deposits, and the utilization of natural gas as a fuel. With so many uncertainties the authors hesitate to attempt any estimate of the world's total oil in any more detail, and instead have attempted to anticipate the possible position in twenty years' time. Having studied the current exploration trends throughout the world and having made as generous allowances for new discovery as are thought reasonable under the circumstances, the following table is arrived at and gives the total of present proved reserves, plus our expectation of new discovery during the period, compared with the present :—

(Million tons)

	Cumulative Production to 1951.	1951, Estimated Proved Reserves.	Proved Reserves (1951 plus new discoveries (1951—1972).
North America . . .	6,256	4,520	10,000
South America . . .	1,163	1,620	5,000
Middle East . . .	644	6,900	20,000
East Indies . . .	200	240	1,000
Russia	952	1,000	4,000
Others	294	170	1,000
Total World	9,509	14,450	41,000

In order to translate this figure into remaining reserves in 1972, and so into the number of years of world supply which it represents, it is necessary to estimate the production over the period and the rate at its end. Over the past twenty years the world's production has increased at an average rate of about 4 to 5 per cent per year. Projecting a similar increase into the future, the world demand will be 1400 million tons per year in 1972, and the cumulative production from 1952 to 1972 would be about 19,000 million tons. Subtracting this from the total of 41,000 million tons gives an estimate for the remaining proved reserves in 1972 of 22,000 million tons or sixteen times the estimated annual production at that time. This figure compares with the present 1952 position of proved reserves, being twenty-four times the current production.

It is clear from this estimate of discovery results in this twenty-year period that it is not anticipated that any new oil area of *major* importance will enter the list. It may be argued that, with so many areas only lightly explored, surprises must be expected, but there is always a reason for less intensive search, in some cases geographical, in others economic or political. These reasons will continue to retard exploration throughout our period of study, and it must be realized that in adverse physical circumstances, whether in the headwaters of the Amazon, in the Sahara, or in the forests

of Papua, ten years or even twenty may be needed in the exploration and exploratory drilling phase before successful discovery can add importantly to the total of proved reserves. All in all, therefore, it is felt that the increase which we have allowed under the heading of "others" to 1000 million tons is sufficient to take care of new discovery, but even if this figure were doubled or trebled the amount would still not affect the major issue.

It is not questioned that in 1972 there will still remain large amounts of oil still awaiting discovery, but, if the figure of world demand is reasonably true, a most intensive exploration effort will be required to maintain the forward reserves position. Such a limited reserve in immediate sight with such an uneven distribution will be a matter of important concern for a world depending more and more on mechanization for its manifold purposes. It is possible, even probable, that oil won from solid sources, coal and oil shale, will increase progressively, or that other sources of energy will gradually displace the oil age, perhaps within the span of the present century.

Discussion

T. Dewhurst: We are very fortunate in having a paper on this very important subject, and doubly so in that it is backed by the wide knowledge and extensive explorations of the authors.

The subject is of great interest to petroleum technologists, to all engaged in the petroleum industry, and to all users of petroleum products. It is important to all mechanized countries in times of peace, and vital to their survival in times of war.

I think the authors have been wise in not attempting to estimate the total oil reserves of the world, as that subject is too big and speculative to be dealt with in a single paper, and would entail the estimation of the reserves of very remote areas, such as Northern Siberia for example, and also of shallow continental shelves which are contiguous to exposed oil-bearing territory. I would suggest that the very big and important problem of the estimation of the total oil reserves of the world might occupy a permanent place in the programme of the World Petroleum Congress. This would enable experts to present estimates of the oil reserves of the particular regions with which they are most familiar, and the total of such estimates would give the best appraisal of the total world reserves. The estimates could be reviewed and revised as necessary at each Congress.

The authors are therefore wise in limiting their estimates to present proved reserves and those likely to be discovered within the next twenty years, as such new discoveries are likely to be in the main oil-producing regions of the world and therefore favourably placed for rapid economic development. However, these limited estimates tend to restrict discussion and to check controversy.

The estimates seem to be cautious and reasonably accurate. I notice that new discoveries in North America are expected to be rather more than the present proved reserves, and presumably Canada will figure prominently in those discoveries. In the case of South America, new discoveries are expected to be about twice the present proved reserves. This estimate

should be possible of attainment in the next twenty years, and indeed should be much exceeded over a longer period.

In the Middle East discoveries are expected to amount to twice the present proved reserves. However, the present proved reserves are so enormous that the estimate seems to place a large degree of responsibility on the region. Nevertheless, the authors possess exceptional knowledge and experience of the geology and oil prospects of the Middle East, and are confident that their forecast could be realized.

In the case of the East Indies, the discoveries during the next twenty years are estimated to disclose more than treble the present proved reserves. This estimate seems to be on the high side, even allowing for the fact that the present proved reserves are small compared with those of other regions.

The word " others " in the paper seems to be somewhat of an understatement for Australia, New Zealand, China, Japan, Burma, India, Pakistan, the greater part of Africa, most of the countries of Europe, and other areas. It must have been a very difficult matter to estimate the new discoveries in these very large areas during the next twenty years, and there is probably some uncertainty about the estimate which was almost five times the present proved reserves.

I agree with the authors that the time will come when the U.S.A. will turn to other sources of oil production. Opinion in the U.S. as to indigenous reserves of petroleum has in the past fluctuated widely from undue optimism to undue pessimism according to the rate of discovery of new fields. When discoveries fail to maintain proved reserves, the U.S. will be driven to attempt to produce oil from oil shale and coal. Their resources of oil shale and coal are very large, and doubtless they will reduce the cost of producing oil from these sources when the need arises. The creation of the huge synthetic rubber industry in a few years time shows what that country can achieve under the compelling spur of military necessity.

Much has been said and written about President Truman's Fourth Point, which is that the advanced nations should help the undeveloped and underdeveloped countries of the world to develop their resources. I consider that the oil industry can be very proud of its record in this respect, as it has done more than any other agency could possibly have done for the discovery and development of the resources of some undeveloped and underdeveloped countries. There should be greater knowledge and appreciation of the serious financial hazards of oil exploration, and of the very high standard of scientific research and technical " know-how " which is required to discover and develop oilfields to the maximum advantage of all concerned.

We are much indebted to the authors for a most excellent and valuable paper, and I can assure them that it will be studied closely and with great interest when it is published in its final form.

Dr W. L. F. Nuttall : With regard to the conclusions in the report of the McCollum Committee I am inclined to share Dr Lees' view that it is most optimistic to prophesy that the U.S.A. can meet its requirements of crude oil as far into the future as can be seen at present. Dr Lees has pointed out that during the last few decades the U.S.A. has been more

actively explored than any other country in the world, and for this purpose new techniques have been developed and applied at great expense. The result has been that during the last thirty years the proven reserves of crude oil have increased from 7800 to 27,500 million brl, with production increasing from 472 to 2244 million brl. An examination of corresponding figures over intervals of ten years shows that in 1921 proven reserves represented seventeen years' production in that year, in 1931 this became fifteen years, dropped to fourteen years in 1941, and twelve years in 1951. It is thus evident that the rate of discovery has not been sufficient to maintain the ratio of reserves to production.

Another matter which has been referred to in the authors' paper has been the failure to find oil in the part of Ecuador east of the Andes. In this connexion I would suggest that the empirical method of calculating the number of cubic miles of sediments in a sedimentary basin and thereby estimating the possible oil reserves may be fallible, since it does not take into account all the important factors. There may be exceptions to this empirical formula, where for some reason oil may have never been generated or if formed may have escaped or be represented by natural gas only. Perhaps the Oriente of Ecuador and Queensland are such exceptions. On the other hand, there is no doubt that in some areas, such as the Middle East, geological conditions must have been exceptionally favourable for the generation and accumulation of oil.

Lastly, the authors have placed the proven reserves of Russia at 1000 million tons. It would be interesting to have Dr Lees' views on the basis for this figure.

Dr Lees : We agree with Dr Nuttall that one cannot apply the square mile factor indiscriminately, but if one takes a large enough area there is a chance that it will average out. The leaner areas will be offset by the richer areas, and when one is speculating over a wide enough area it is a possible way of doing it. Of course, we know from experience that some areas are enormously richer than others and it is possible for the estimate to be widely out locally.

We have merely taken Ecuador as an example to show how an area can be sterilized for oil search by an unsuccessful attempt under present-day circumstances. It means that such oil as it may have will not be found for many years to come.

It is, of course, extremely difficult to estimate what the Russian reserves may be, but one has a certain guidance from their present rate of production of about 42 million tons a year. We know that, in most fields on steady production, the maximum a well can give is a certain ratio of the reserves in the ground. A reasonable figure for fields fairly advanced in their producing life is 5 per cent, and if Russia is producing at that rate one has a possible way of estimating what the reserves may be.

In 1937 Goubkin made estimates of Russia's reserves divided into probable and possible categories. There has been no authoritative estimate of Russian reserves since then.

Would Dr Nuttall agree that for proved reserves the 5 per cent production rate basis was reasonable ?

DR NUTTALL: I agree it is, but there may be areas which are not in full production.

DR LEES: I agree there may be, but the bulk of their production is coming from fields already in an advanced state of decline.

H. R. LOVELY: Has Dr Lees in his calculations considered the continental shelves? Recently there has been a lot of discussion on the oil content of the continental shelves. There is quite a possibility that considerable reserves exist offshore in America and Mexico, and it is quite possible also that the present optimistic effort of the Americans may be based partially on the development of those offshore areas.

DR LEES: We have taken the continental shelves into consideration to a limited extent. The discovery of oilfields 20 to 30 miles offshore is an outstanding achievement, and undoubtedly there are many oilfields to be found in areas where a zone of oilfields onshore can be projected out to sea. We do not believe that a continental shelf, because it is a continental shelf, is necessarily oil bearing. If the rocks and structure on the adjacent coast are unfavourable, there is no reason to believe that the actual explanation of the geological structure seen on dry land is any different out at sea. For instance, there has been no exploration of the Atlantic sea-slopes of the U.S.A. Some dry wells have been drilled on the coast, and until some oil is found on the dry land of the eastern seaboard of the U.S. no oil company will venture seawards. Elsewhere in the world there are some places where the continental shelf has to be taken into consideration, but by and large there are few such areas. In the twenty-year period we think that only a very small proportion of the total will come from the continental shelves.

H. P. W. GIFFARD: Can Dr Lees find time to say a few words about the prospects of the British Commonwealth and Empire, in particular on such places as Trinidad, Barbados, and all those islands?

There is, of course, Canada. Africa, on the map, looks terribly blank from the oil point of view.

DR LEES: I agree that Trinidad might produce some surprises. Barbados has some possibilities. There are possibilities in some African territories, such as Nigeria. Australia, including Papua, and New Zealand also have possibilities, but the expectation from them is unimportant on a global scale.

Mr Dewhurst has criticized the point of the smallness that we have given to expectations from other countries in the twenty year look ahead. We are quite willing to double that figure if Mr Dewhurst wishes, but even then it would not make any important difference to the major supply problem of the world. A field in Barbados might be extremely important to Barbados and its economy; and a field in Nigeria would be important to Nigeria and to the British share of oil production, but its effect on the total supply position would be small.

Canada is included geographically with the U.S. under North America. It has, of course, great possibilities but not oil richness by Middle East

standards. All the oil so far discovered, distributed through dozens of individual fields, would easily fit inside one single Middle East oilfield with quite a lot to spare, so that one should not get Canada's importance out of scale, great though it undoubtedly is.

A. BEEBY-THOMPSON : Can Dr Lees say anything regarding the gas production of the world and the main uses to which it is put ? Only some gas is being used for the extraction of gasoline, and much is not being treated for the recovery of the condensable content. The condensable liquid petroleum products of the world must be enormous and constitute a valuable reserve.

I understand that water drive is the determining factor in the recovery of oil from the Persian and Irak fields. If that is so, one cannot help wondering where the necessary water will come from to sustain the pressure and maintenance of supply as is the case on the Golden Lane oilfields of Mexico.

DR LEES : We have not dealt with the gas reserves. In most oil-producing areas the gas reserves are approximately equal to the oil reserves in total thermal value. The enormous gas reserves of the world may eventually be turned to use if our refining men can improve their technique just a little bit more to make liquid fuels from methane at competitive prices ; then the products from those enormous gas reserves will help in the world supply position, particularly in remote countries where there is no immediate demand for gas. In the U.S., of course, gas finds a ready market, but in so many desert or tropical countries gas, as a rule, has no present-day value, but it would be most important and would help the forward supply position considerably if gas could be used in the future.

As regards the Middle East fields, some have water drive and some have not. Some are produced by expanding gas drive. The fields on the Arabian side are more likely to have water drive, and the water drive may give a better recovery factor than gas expansion. The more porous the limestone the better the recovery factor from water drive.

B. N. DARBYSHIRE : To what depth does Dr Lees consider it will be necessary to drill in order to reach the deepest reserves of oil in the world ?

DR LEES : We know that there are some sedimentary basins having a rock column of 30,000 or even 50,000 ft. But it is debatable whether conditions at these depths will be as favourable for oil accumulation as those at shallower depths. The porosity of the rocks probably decreases with depth so that one may not get a corresponding benefit in direct proportion to the additional drilling. The hazards of the search will also increase with increasing depth.

MR DARBYSHIRE : Is the increasing heat at greater depth likely to be a limiting factor ?

DR LEES : Not as far as experience has gone. Increasing temperature is a factor, but against it could be put increasing pressure, which is likely to be more troublesome.

R. E. MARTIN : In his talk Dr Lees dealt with the distribution of the

oilfields of the world—that is, the distribution of the " oil in place," and he mentioned that the recovery of this " oil in place " was likely to be of the order of approximately 25 to 30 per cent. The recovery factor is, however, vitally important, as we are more concerned with the oil we can get out of the ground than with the oil remaining there. If, for the sake of argument, the recovery factor is taken as about 30 per cent, a figure which had been reached in many fields in the past, it seems possible that by the application of new techniques this figure might be doubled. An improvement from 30 to 60 per cent could well be imagined. Some fields in the States are working very actively on the problem. Economics will have to be considered, and there is understood to be one field where it has been found worthwhile to produce 15,000 b.d. of water containing only 2 per cent of oil from the individual wells.

If we could develop reservoir engineering techniques it seems that world reserves can be greatly improved, simply on account of greater recovery and irrespective of the number of new fields which might be found.

Dr Lees : This is so. In the figures of proved reserves, of course, the benefit of secondary recovery is to a certain extent taken care of. The American system of estimating proved reserves and revising them from time to time includes an estimate of any improvement in recovery technique in any particular field and as it is found to be applicable to more and more fields. Of course, secondary recovery does not work in all fields. It is impossible to generalize until particular cases have been tried, but as we have said, it is a matter of economics. In some cases it is profitable to produce 99 per cent of water for the sake of 1 per cent of oil. The length of time that this will continue depends on the economics of production. Undoubtedly there will be improvements as time goes on, but by and large a certain percentage will be left behind and it is very difficult to say whether this may be 25, or 30, or 40 per cent.

However, in our forward estimates of oil likely to be recovered in the next twenty years, improvements in recovery had been considered, and an improved recovery of 50 per cent would not increase our estimate by 50 per cent.

Professor V. C. Illing : I wish to compliment Dr Lees on the very capable way in which he has handled a most important but difficult subject. I realize all too well the pit-falls which await anyone treading in these paths, and the questions I would like to ask Dr Lees are framed with the expressed purpose of illustrating some of the broad factors which must inevitably colour each geologist's personal view when he discusses the problems of reserves. These factors are some of the debatable points still not agreed among geologists, which inevitably must affect their views about the future prospects of finding new reserves.

One of the reasons why it is so difficult to make any estimate is that we are dealing with recoverable reserves, not oil in place, and there is a great difference between the quantity of oil in place and the quantity of oil that can be recovered. In an extreme instance one might take the case of the quantity of crude oil probably locked up in the formations of marine shales, etc., in a country like England, where there can be no doubt that there are

enormous quantities of oil within the shale masses, but only a small quantity has been left in the potential reservoirs. On the other hand, if our consideration is limited to bona fide oil-reservoir rocks, the oil that can be recovered from these rocks depends very much on factors such as porosity and permeability, and also on the methods by which the oil is recovered. Hence, as we are dealing with recoverable oil reserves, there is in the future a very considerable opportunity for additional recovery from reservoirs which have already been semi-exhausted by normal methods of recovery, but which are available for the introduction of additional recovery methods.

Dr Lees, when talking of the tremendous reserves of oil available in the Middle East, clearly holds the view that there is no other part of the world with similar potentialities, and in discussing this point, he appeared to me to have laid undue stress on the size of the anticlines as being the main factor responsible for the phenomenal stores of oil. In his view this is the one factor which made the Middle East unique. In my view it is more probable that whilst undoubtedly the sizes of the structure have played their part, what is of more importance is the presence of a unique cover, the shales and the salt and gypsum which overlie the main reserves of oil in that part of the world. This is a unique cap rock impervious to all oil escape, and it seems to me that it is this particular factor that is in the main responsible for the tremendous accumulations of oil preserved in the area. This being so, I am not dogmatic enough to assert that we should not in due course, and at considerable depths, discover enormous oil sources below other original salt layers or under the clays of some of the deeper unexplored sedimentary basins.

Turning to the question of estimating the reserves of any area by computation of the normal quantities of oil per square mile, I feel that such methods have little value, for there are such enormous differences between the concentration of oil in some areas and others. Take, for instance, the Caspian, where in a region of about 180 square miles the concentration of oil must be something of the order of 2 to 3 million tons per square mile. Other regions such as the Maracaibo basin and parts of the Gulf States are also typical examples of the high concentration of oil in certain areas of favourable sedimentation. It is this particular factor which must be apparent to any careful geologist when he attempts to forecast the future for many of the great sedimentary basins, the depths of which are still relatively unexplored. They are examples of the importance of the protection of oil from the dispersive processes of nature, but they are also areas which need deep drilling, and many of them are potential areas that in the future could produce surprises for even the most optimistic geologist, and must be allowed for in all calculations. It was a thought of this nature which had undoubtedly affected geologists in the United States. In their recent calculations the oil reserves attributed in the world would appear to be very high indeed, but our American colleagues know what they are talking about, and whilst their statements may appear flamboyant, I would not regard them as impossible.

There is one feature in Dr Lees' forecast with which I am not altogether in agreement. This is his estimate of the probable increase in oil reserves for North America over the next twenty years. Bearing in mind the fact that we are dealing with recoverable reserves and many of the earlier oil-

fields were poorly produced, also that there are still some of the deep basins relatively unexplored and some interesting marine areas still to be explored, it seems unwise to place the potentialities for increase at as low a figure as they have done.

Future reserves are governed by economics, and if there is one feature of the treatment of their subject by the authors which calls for special comment, it is the very useful consideration of what position we will be in twenty years hence. This is in fact a more important and probably a better way of regarding the oil industry's future than a mere estimate of reserves, because there can be little doubt that when the oil industry has begun to approach the point at which it becomes more difficult to find new oil, economic factors will take charge and new methods of oil recovery will receive greater attention. Furthermore, the industry will begin to look more closely into the potentialities of oil shale and other sources of energy as they are already doing. It is likely, therefore, that there will be a long period of slow transition during which oil will gradually fall out of the picture and be replaced by other sources of power. Dr Lees has done a considerable service by drawing attention to this feature.

DR LEES : I agree with a number of Professor Illing's general comments, but I do maintain that the great size of the anticlines in the Middle East is most important. The richness of the area is so great that most of the reservoirs are full to their limit. If the anticlines had been even greater than they are, then the oilfields might have been still greater.

The excellence of the anhydrite-salt cap rock of Persia and Eastern Iraq is certainly an important factor, but the cap rocks of South-west Iraq, Kuwait, and Arabia are of normal type, shales in some cases, anhydrites in others, but again the anticlines are large.

I am quite conscious that the method of computing oil reserves as so much per square mile is one which cannot be rigidly applied, and the example of the Apsheron Peninsula on the Caspian which Professor Illing quoted is a good example of exceptional oil richness, even though the gathering area from which the oil has accumulated may extend beyond the confines of the peninsula itself. We have discussed the productivity yardstick in general terms, but have exercised commendable restraint in not attempting any firm estimate of the ultimate reserves of the world.

We agree with Professor Illing in his high regard of the worth of our American colleagues, but we still consider that the implication of the recent McCollum Committee of the National Petroleum Council is over-optimistic for the U.S.A. We believe that we have allowed in our forward estimate for a discovery rate for North America as a whole which will cover those unknowns which Professor Illing mentions.

THE CHAIRMAN said he thought they would all agree that Dr Lees had given a most valuable paper and hoped they would all join with him in a hearty vote of thanks to Dr Lees for a talk which he hoped they had found stimulating. The problem with which he had dealt was one which could not be dismissed by a discussion in one evening.

The Chairman's proposition was received with acclamation and the meeting concluded.

FLUID CATALYTIC CRACKING WAX DISTILLATES FROM MIDDLE EAST CRUDES

By The Research Staff of the Anglo-Iranian Oil Company Ltd.

Summary

This paper discusses the results obtained in cracking heavy distillate fractions from Middle East crude oils, over synthetic silica–alumina catalyst, in a 2-b.d. fluid catalyst pilot plant. A simple but practical correlation of product yields and qualities with conversion in both once-through and recycle operation is given with respect to a typical wax distillate feedstock. The differences to be expected with different crude sources are discussed with reference to the results obtained from cracking similar wax distillates from four major fields. The effect of varying the feedstock boiling range within a given crude is illustrated by a systematic study on three consecutive fractions and on blends of these fractions. In all cases the results are examined in relation to the full-scale processing at the maximum coke-burning capacity of the regenerator. The effect of conversion and feedstock on the sulphur distributions of broad and detailed liquid fractions are shown, as well as the distribution of both bromine and octane numbers in the gasoline boiling range.

Introduction

The fluid catalyst pilot plant at the Research Station of the Anglo-Iranian Oil Co. Ltd. was constructed to investigate the cracking of heavy feedstocks derived from Middle East crude oils. The main interest was in the behaviour of wax distillates in the approximate true boiling range 300° to 550° C, for which, at the inception of the work in 1946, there were practically no published data. A systematic investigation of the effects of process variables and feedstock boiling range was carried out using a silica–alumina type 3A catalyst. Although the scope of the work was wide, the conditions chosen were in all cases within the range of commercial operations. The results of the studies were correlated with respect to the operating variables and feedstock characteristics, but the detailed correlations were complex, and their presentation is outside the scope of this publication. The more important and general conclusions are presented, however, in a form which is of value in the design and operation of commercial units processing Middle East wax distillate feedstocks. The results given are principally concerned with once-through operations, in which fresh feedstock only is processed, but limited data on the effect of recycling are also included.

Extrapolation of Pilot-plant Data

The data obtained from the fluidized-bed pilot plant cannot always be directly applied to a large-scale operation. Thus, for example, the feedstock conversion achieved in the pilot unit would not be duplicated in the commercial unit, although the same basic conditions of temperature, pressure, space velocity, and catalyst : oil ratio were used. It is found, in fact, that the overall reaction severity required in a commercial fluid

cracking unit is less than that required in a pilot unit. This difference in apparent reaction rate is due mainly to the greater catalyst-utilization efficiency and to the use of a smaller percentage of inerts in the commercial unit. For the type of feedstock under consideration the rate of cracking is, however, only of secondary importance, since it is estimated that the reaction space required is, approximately, only one-tenth of that necessary in the regenerator for the combustion of the coke produced. Hence, with these feedstocks, which require such low severities for cracking, the reaction vessel presents no difficulty since, in order to provide flexibility, a conventional catalytic cracking reactor is normally designed to deal with feedstocks, such as gas oil, which are much more refractory than wax distillates. With these heavy feedstocks, therefore, the problem becomes basically one of coke-burning. The regenerator is operated to its maximum

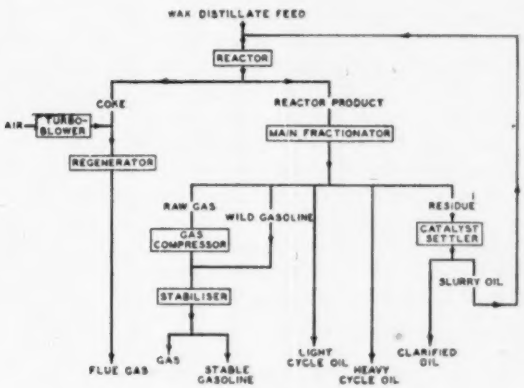


FIG 1

FLOW DIAGRAM

capacity, and the throughput, recycle ratio, or feedstock conversion is adjusted so that the coke production fulfils this condition. After the regenerator the next limitation in plant capacity is usually that of gas production. The cracking system is normally operated at 5 to 10 p.s.i.g., and hence, for effective gasoline recovery and stabilization, a gas-compression stage has to be incorporated between the main fractionator and the gasoline-recovery system. The relation of these two items, the regenerator, with its associated turbo-blower, and the gas compressors, to the overall process is illustrated in Fig 1.

The main value of the results from pilot-plant operations on wax distillates lies, therefore, in the information which they can provide with regard to the product yield distribution and the qualities of the products, and in the applicability of such information to large-scale operation. In this respect the results of a comparative test carried out by Universal Oil Products Company * are of particular interest. In this work the actual catalyst and feedstock used in a commercial test run were transferred to a

* *Refiner*, 1947, **26** (11), 104.

pilot unit in which the process conditions were set to give the same feedstock conversion, that is, the comparison was made on the basis of equal conversion and not on the basis of identical operating conditions. It was found that with the exception of the coke production, the yield and product-quality data were practically identical in the two test runs. The coke yield, as a weight per cent on feed, was, however, in this particular comparison, 0·8 less in the pilot unit than in the commercial unit. The difference in coke production is mainly due to the fact that the stripping of the absorbed or entrained hydrocarbons from the spent catalyst is much more efficiently carried out in the pilot than in the commercial unit. It is difficult, without direct experiment, to make an estimate of the relative coke yields from the two scales of operations, particularly in the case where the large-scale plant is only in the design or construction stage. Prediction methods are available, but the uncertainties are such that, for the purpose of the present data, it is considered sufficiently accurate to obtain the large-scale coke yield by a conventional addition of 1 per cent weight on oil-feed to the corresponding pilot-plant value. Strictly, the correction made should be a function of the catalyst : oil ratio, and the adopted value of 1 per cent is an average value for ratios in the region of 6 to 10 and for a slurry return of not more than 2 per cent by weight on fresh feed.

In order to emphasize the coke-burning and gas-compression limitations the yield data given includes, in all cases, the gasoline, C_4, and dry gas production for a regenerator of a given coke-burning capacity. The basis selected for such data is a regenerator capable of burning 10,000 lb of coke per hour, which corresponds to a medium-size commercial unit with an oil-feed throughput of 10,000 to 15,000 b.s.d.

Catalysts and Feedstocks

The catalyst charged to the pilot unit was a synthetic material of the silica–alumina type. Two batches were used, the activity ratings being practically identical. Both were obtained by withdrawal from a large-scale fluid-cracking unit operating in the U.S.A., and were, therefore, typical of the equilibrium state reached in the process. In order to assist

Table I

Properties of Catalysts

		Batch A	Batch B
Activity rating	D + L units	22	22
Gas-producing factor		*ca* 2·2	*ca* 1·8
Carbon-producing factor		*ca* 2·2	*ca* 1·8
Surface area (B.E.T.)	sq. m/g	84	74
Particle size analyses :—			
0–20 μ	% wt	5	2
20–40 μ	,,	26	26
40–60 μ	,,	22	28
60–80 μ	,,	18	19
80 plus μ	,,	29	25
Iron content (as Fe)	,,	0·26	0·13
Sodium content (as Na)	,,	0·06	0·09

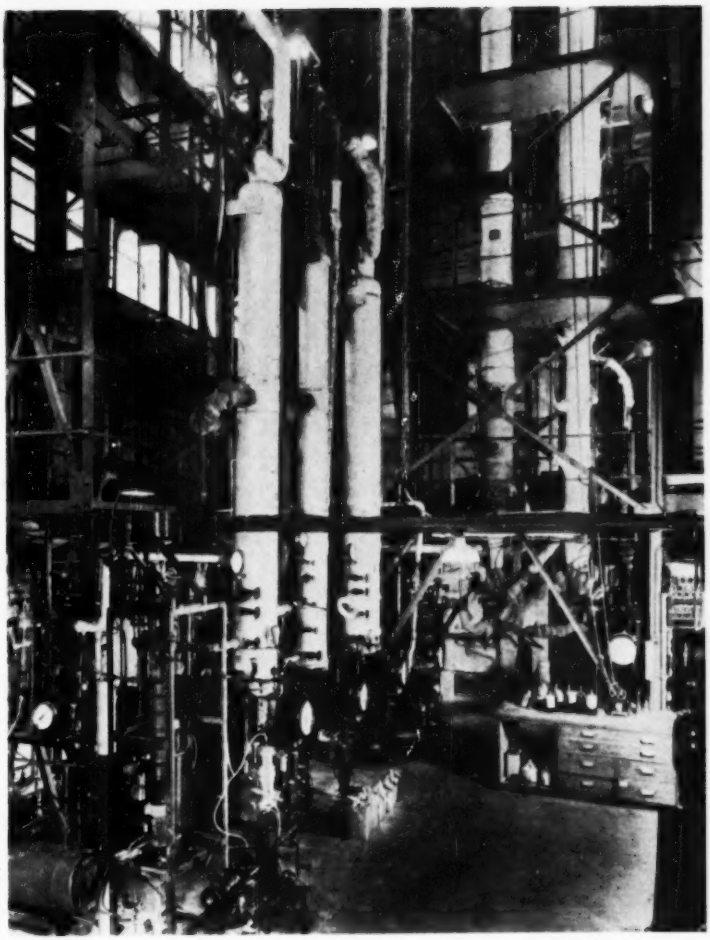


FIG 2

2 B.D. FLUID CATALYTIC CRACKING PILOT PLANT

[*To face p.* 938.

catalyst flow in the standpipes the fines content of the samples received was reduced before use in the pilot plant. This was achieved by air-elutriation. Inspection data on the catalysts used in the pilot unit are given in Table I.

Results are given in this paper for the processing of nine different feedstocks over the above catalysts. The properties of the materials are given in Table II. They were derived from the crude oils of four major Middle East fields, designated A, B, C, and D, respectively. All the feedstocks are wax-bearing fractions prepared by vacuum distillation.

Equipment and Process Conditions

A photograph, Fig 2, shows the general lay-out of the downflow fluid-catalyst pilot unit, and a simplified flow diagram is given in Fig 3.

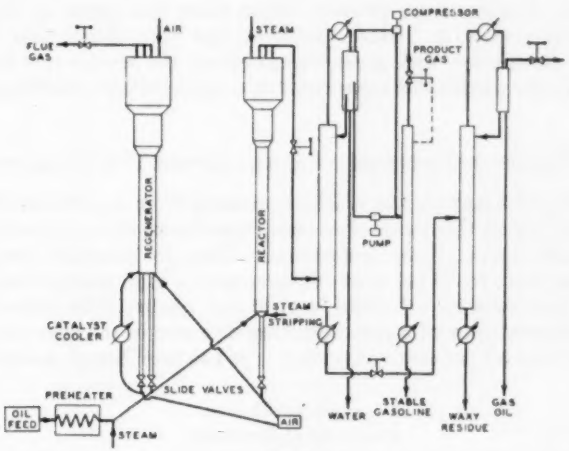


Fig 3

FLUID CATALYST CRACKING PLANT. SIMPLIFIED FLOW DIAGRAM

The wax-distillate feedstock is preheated, mixed with steam, vaporized, and then passed into the catalyst transfer line to the reactor. Decarbonized catalyst is picked up at the regenerator slide valve and the catalyst–oil mass enters the reactor above the stripper zone. Spent catalyst leaves the reactor via the steam stripper, and is carried back to the regenerator by a preheated air stream. The regenerator temperature is controlled by the recirculation of catalyst through the catalyst cooler. The reaction-product vapours and flue gas leave the vessels through porous ceramic filters working on a purge time-cycle system. The fractionation system operates without intermediate storage, and is designed to produce gas, debutanized gasoline, vacuum gas oil, and a waxy residue.

In general, the variation of conversion, or depth of cracking, was obtained by adjustment of the quantity of catalyst in the reactor, that is, by the space velocity. In comparison with this variable the remaining process conditions were practically constant. Thus, the reactor top pressure was 10 p.s.i.g.

and the reactor dilution was 13 per cent by weight as equivalent steam. The reactor temperature was maintained at 930° F for conversions up to approximately 60 per cent and at 950° F for conversions in excess of this value. These temperatures may be regarded as typical for low- and high-conversion operations, respectively. The trend in catalyst : oil ratio was similar, a value of 4 : 1 to 6 : 1 being employed for the lower conversions, and 6 : 1 to 10 : 1 for the higher levels. In the tabulated and graphical data no corrections have been made for these variations in temperature and catalyst : oil ratio.

Apart from coke and dry gas, the pilot-plant products are defined on the basis of true boiling points in a fourteen-plate column distillation of the total liquid product from the reactor. This liquid product is distilled to give three liquid fractions corresponding, respectively, to a debutanized gasoline (C_5 to 430° F), a gas oil (430° to 635° F), and a residue (above 635° F). This division of the reactor product differs from that given in Fig 1 for a typical commercial unit. Since, however, the pilot-plant yield data are based on a distillation with good fractionation, the results can be readily translated to the distillation equipment of a commercial installation.

The Effect of Conversion Level—Single Pass Operation

The yield and nature of the cracked products from a given feedstock are affected not only by the depth of cracking but also by the process conditions used to obtain the particular conversion. Thus, for example, the products from an operation to 55 per cent conversion at a high reactor temperature and high space velocity will differ in yield and quality from those obtained at a low temperature and a corresponding decrease in the space velocity to obtain the same 55 per cent conversion. It has been found, however, that,

Table II

Properties of Feedstocks

Crude Source	Field A						Field B	Field C	Field D
Ref. No.	A.1	A.2	A.3	A.4	A.2/3	A.3/4	B.1	C.1	D.1
Sp. gr. at 60° F	0·916	0·874	0·913	0·944	0·893	0·929	0·911	0·927	0·912
Total sulphur % wt	1·77	1·33	1·68	2·13	1·47	1·85	1·59	2·90	2·17
Kinematic visc at 140° F cs	18·97	3·78	15·19	95·8	7·07	36·07	18·25	24·60	14·34
Carbon residue (Conradson) % wt	0·95	0·05	0·11	2·5	0·07	1·4	0·25	1·4	0·52
Aniline pt ° C	85·1	72·5	83·5	91·6	78·0	87·8	—	—	82·1
Wax (methylene chloride) % wt	12·7	7·3	12·2	12·4	9·5	12·2	14·0	9·4	10·8
M.p. of wax ° F	129	100	121	147	112	135	127	130	112
Diesel index	43·5	49	43	36	47	40	—	37	44
Distillation (Vacuum Engler) * :—									
I.B.P. ° C	306·5	—	331	328	—	327·5	308	330	303
5% vol at ,,	344	266	365	453·5	290	374	374	356	338
10% ,, ,,	354·5	285	378	472	306	393	384	366	351
50% ,, ,,	446	336	427	525	388	478	434	454	433·5
80% ,, ,,	517·5	370	464	571	436	547	488	538	503
90% ,, ,,	554·5	385	480	596	—	574·5	512	—	543·5
F.B.P. ,,	—	420	525	633·5	—	601	540	—	597·5

* Corrected for emergent stem and to 760 mm pressure.

in general, the reaction products are primarily dependent on the feedstock conversion and that the various combinations of process conditions which can be used to attain any given conversion have only a secondary effect. The most convenient method of adjusting conversion, both in large-scale and pilot units, is to vary the space velocity, that is, the quantity of catalyst in the reactor, and only minor adjustments are made to the remaining process variables. Hence, under these conditions the expression of the yields and properties of the products as a function of conversion will give a good practical correlation of the data. The results of such a correlation are given in Figs 4 to 12, inclusive, with reference to a typical wax distillate feedstock (A.1 of Table II) derived from a major Middle East field and processed in the Sunbury pilot unit over a synthetic catalyst.

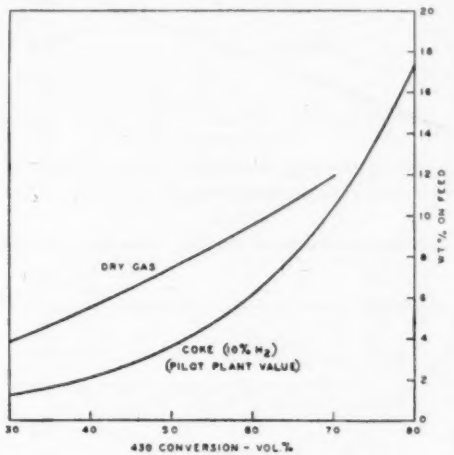


FIG 4

FIELD A WAX DISTILLATE—PRODUCT YIELDS. COKE AND DRY GAS (EXC. H_2S)

The effect of conversion on the yields of the cracked products may be exemplified by the comparative tabulation (Table III) which gives the effect of increasing the conversion from 45 to 55 per cent.

Thus, the outstanding effect of increasing conversion is to cause a rapid

TABLE III

Product	Yield, % wt on feed		Percentage change
	at 45%	at 55%	
Coke	2·7	4·7	74% increase
Dry gas	6·4	8·4	31% ,,
Total C_4	6·3	8·6	36% ,,
Gasoline	29·2	32·4	11% ,,
Gas oil	19·1	18·1	5% decrease
Residue	36·4	27·8	24% ,,

increase in the coke production with but little increase in the gasoline yield. The gasoline correlation line, Fig 5, shows that there is little or no gain in the

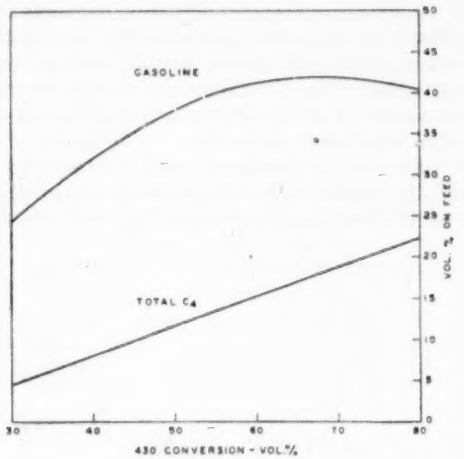


FIG 5

FIELD A WAX DISTILLATE—PRODUCT YIELDS. TOTAL C_4 AND GASOLINE

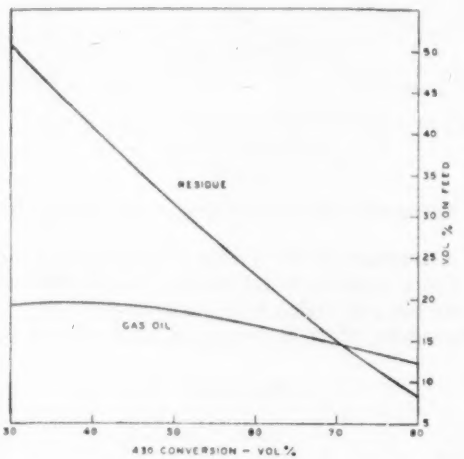


FIG 6

FIELD A WAX DISTILLATE—PRODUCT YIELDS. GAS OIL AND RESIDUE

yield at conversions above 60 per cent and that the yield decreases above 70 per cent conversion. This latter effect is due, presumably, to the increased refractoriness of the unchanged feed and the corresponding relatively increased secondary cracking of the product.

The variation of the detailed composition of the dry gas (C_3 and lighter) and total C_4 fraction with conversion are given in Figs 7 and 8 respectively. The general effect of conversion is to render the dry gas more saturated, to

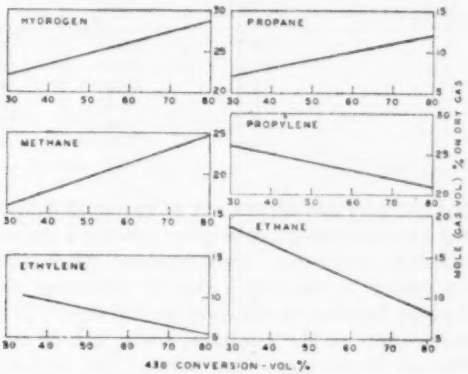


FIG 7

FIELD A WAX DISTILLATE. COMPOSITION OF DRY GAS (GAS VOLUME PER CENT)

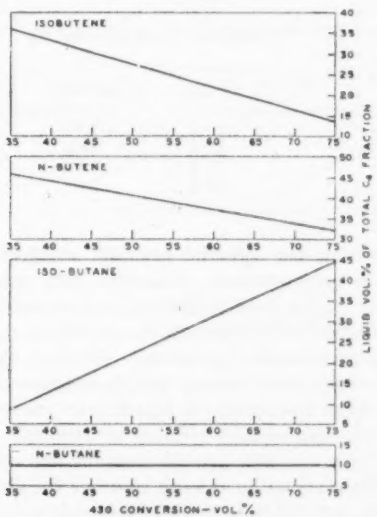


FIG 8

FIELD A WAX DISTILLATE. COMPOSITION OF C_4 FRACTION LIQUID VOLUME PER CENT

increase the proportion of hydrogen, methane, and propane, and to decrease that of ethane. The magnitude of the effects are shown in the following tabulation (Table IV), which gives the changes caused by increasing the conversion from 45 to 55 per cent.

TABLE IV

Component	Gas % vol on dry gas		Percentage change
	at 45%	at 55%	
Hydrogen	24·1	25·5	6% increase
Methane	18·6	20·5	10% ,,
Ethane	15·4	13·1	15% decrease
Ethylene	9·0	8·0	11% ,,
Propane	8·5	9·5	12% increase
Propylene	24·4	23·4	4% decrease

The effect of conversion on the saturation of the total C_4 fraction is similar to that on the dry gas, increasing conversion causing a decrease in both the *n*-butene and *iso*butene contents. An important effect on the C_4 fraction of increasing conversion is the rapid rise in *iso*butane content, a factor which has an obvious bearing on alkylate production. It has been found that, within the accuracy of the analyses, the *n*-butane content of the C_4 fraction is constant at 10 per cent by volume. The variation in the composition of the total C_4 fraction as the feedstock conversion is raised from 45 to 55 per cent may be summarized as in Table V.

TABLE V

Component	Liquid % vol on total C_4		Percentage change
	at 45%	at 55%	
n-Butane	10·0	10·0	Nil
n-Butene	42·1	38·8	8% decrease
*iso*Butane	17·7	26·5	50% increase
*iso*Butene	30·2	24·7	18% decrease

The manner in which the specific gravity, sulphur content, bromine number, hydrocarbon type analysis, volatility, and octane number of the debutanized gasoline varies with feedstock conversion is given in Figs 9 and 10. The broad effect of increasing conversion is to produce a lighter, more volatile, and more saturated gasoline. Further, the aromatic content increases, the sulphur content decreases, and the octane ratings are improved. Hence, in general, a high conversion is beneficial with regard to the quality of the gasoline and the subsequent refining treatments.

The properties of the cracked gas-oil fraction are correlated in Fig 11. As expected from the increase in octane number for the gasoline fraction, the diesel index of the gas oil falls as the feedstock conversion is increased. The trends in the specific gravity and sulphur content are the reverse of those in the gasoline, both showing increases with conversion. The kinematic viscosity of the gas oil falls appreciably as the conversion is raised. The variations in residue properties with conversion, Fig 12, are similar to those in the gas-oil fraction. Specific gravity and sulphur contents show increases and viscosity a decrease as conversion is raised. The correlation line for viscosity shows, however, a reversal at about 60 per cent conversion,

after which a sharp rise occurs until at 75 per cent conversion the viscosity of the residue is higher than the value at 30 per cent conversion.

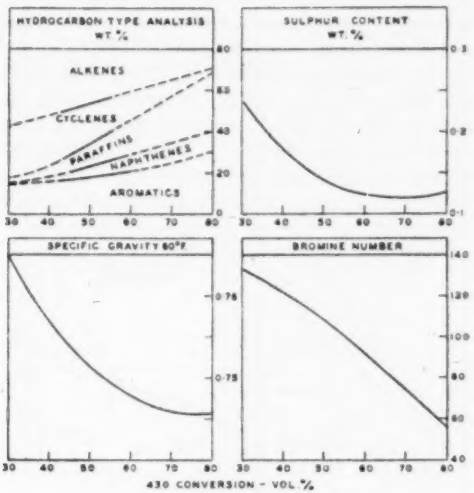


FIG 9

FIELD A WAX DISTILLATE. PROPERTIES OF GASOLINES

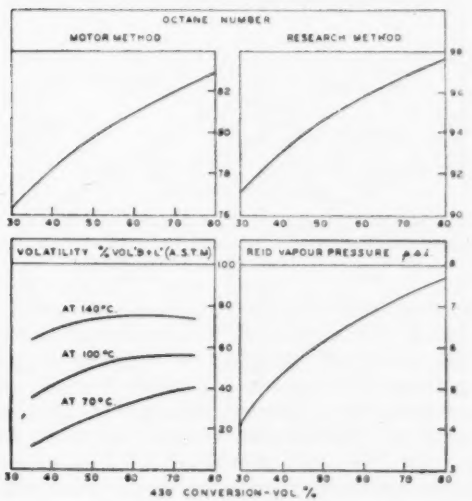


FIG 10

FIELD A WAX DISTILLATE. PROPERTIES OF GASOLINE

The correlation curves given in Figs 4 to 12, inclusive, and discussed above, give not only the effect of feedstock conversion on product yield and

quality but also provide the basic data for the study of production in a commercial unit. It will be realized, of course, that they cannot be applied

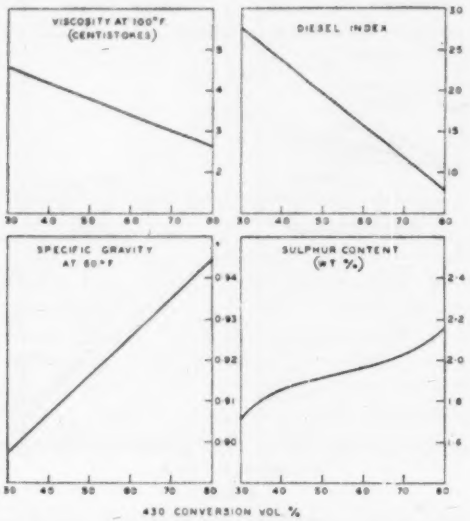


FIG 11

FIELD A WAX DISTILLATE. PROPERTIES OF GAS OIL

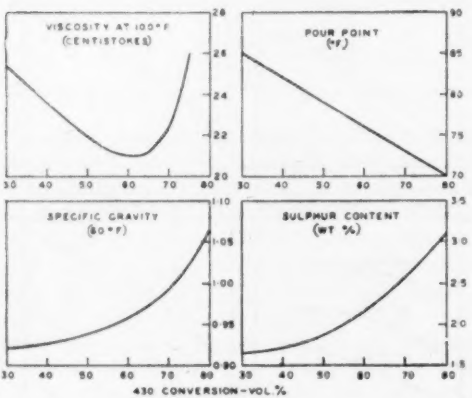


FIG 12

FIELD A WAX DISTILLATE. PROPERTIES OF RESIDUE

directly to such problems, since the yield data refer to percentages on feedstocks and, as such, ignore any limitations in the producing equipment.

As previously discussed, the first limitation in a commercial unit processing wax distillate will be the coke-burning capacity of the regenerator. For

this publication a regenerator capacity of 10,000 lb of coke per hour has been selected for comparison purposes, the large-scale coke yield being taken as 1 per cent weight in excess of the pilot-plant value. On this basis the curves given in Fig 13 have been constructed. It is seen that, provided ample feedstock is available, the production of gasoline is highest at the lower conversion levels, with a possible maximum at about 35 per cent conversion. At this conversion level, however, the gasoline is highly unsaturated with a sulphur content of 0·2 per cent weight and an octane number (motor method) of only 77. The research octane number shows a similar decline, but it will be observed (Fig 10) that the research appreciation is constant, at 14·8 octane numbers, over a conversion range of 30 to

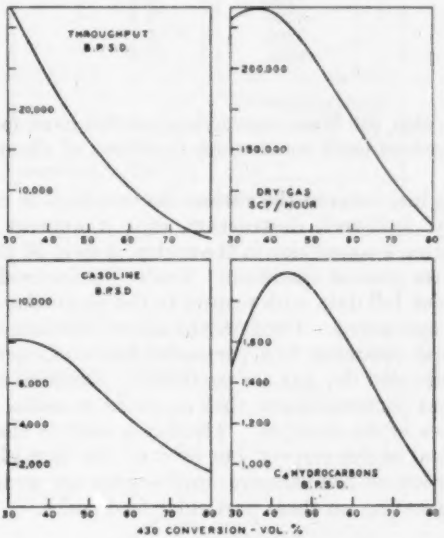


FIG 13

FIELD A WAX DISTILLATE. PRODUCTION FOR 10,000 LB/HOUR COKE BURNING CAPACITY

80 per cent. For other reasons, it may, therefore, prove advantageous to operate at higher conversions, but the data in Fig 13 show that from the gasoline-production aspect, the operating conversion should be kept as low as possible. At conversions below 40 per cent another factor may also prove limiting. This is the linear velocity in the reactor at the very high oil throughputs which are required fully to load the regenerator. If this velocity exceeds about 1·5 ft per second then, with normal-grade catalyst, the reactor cyclone loading will rise rapidly and ultimately overload the catalyst slurry-recovery system. Another feature which is evident is that if the gas-compression equipment is designed for a conversion of 40 to 45 per cent then it will not be overloaded at any other conversion, since the dry gas and C_4 production show maxima in this region (Fig 13).

Where the cracked gasoline is to be used in blend with other components.

the yield–octane–number relation becomes an important factor. Combining the data of Figs 10 and 13, the effect conversion on the barrel-octane numbers (motor method) per day shown in Table VI is obtained.

TABLE VI

Conversion, % vol	Gasoline		Barrel-octane nos. (per day)
	b.s.d.	O.N.	
30	8100	76·3	620,000
35	8100	77·4	630,000
40	7800	78·3	610,000
45	7100	79·1	560,000
50	6200	79·8	500,000
55	5200	80·4	420,000
60	4300	81·0	350,000

On this basis, also, the lower conversions are the more favourable, but the decline is not serious until conversions in excess of about 45 per cent are attained.

Hence, taking into account the various factors, such as catalyst recovery, gasoline quality, feedstock destruction, etc., it appears that for motor-gasoline production a conversion in the region of 40 to 50 per cent will prove to be optimum for general operation. A more precise evaluation cannot be arrived at without full data with respect to the particular unit and to associated refinery operations. Further, the above discussion of the effect of conversion is with reference to a particular batch of equilibrium catalyst. The yields of coke and dry gas are particularly sensitive to the nature and extent of catalyst contamination, that is, to the so-called carbon- and gas-producing factors of the catalyst. The batch used in the present work is reasonably typical in this respect, but even so, the data given in this study should be regarded as comparative until results are available from commercial units operating on these particular feedstocks.

The Effects of Recycling

The foregoing discussion deals with the results of cracking a wax-distillate type of feedstock on a single-pass or once-through basis. This type of operation is generally employed where supplies of fresh feedstock are unlimited. When such a situation does not exist, for example, if the crude-oil supply or vacuum-distillation capacity is restricted, then the maximum amount of gasoline is obtained by recycling. In this case some of the high-boiling cracked products are returned to the reactor along with fresh feed. The extent of recycling obviously influences the general distribution and quality of the products, and the effects were determined in the pilot plant by cracking a material similar to wax distillate A.1 at each of two recycle ratios, over a range of conversions. The cycle stock consisted of the heavy fraction boiling between gas oil and a heavy slurry oil residue.

The detailed effects on product yields and gasoline quality at any conversion level are shown with reference to the single-pass cracking of wax

distillate A.1 in Figs 14 and 15. A typical comparison between single-pass and 1·25 recycle ratio operations at 50 per cent conversion is made in Table VII, both the yields and conversions being expressed on a *fresh* feed basis.

Thus the outstanding features of recycling, under fixed fresh feed conversion conditions, are the reduction in coke yield by 15 per cent and the

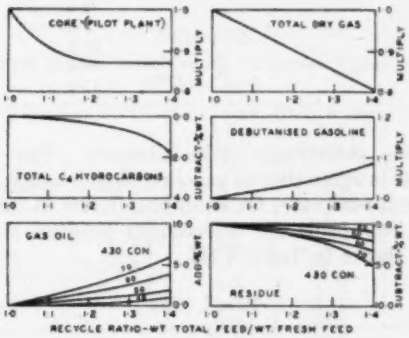


FIG 14

EFFECT OF RECYCLING ON PRODUCT DISTRIBUTION. CORRECTIONS TO SINGLE PASS YIELDS/FRESH FEED BASIS

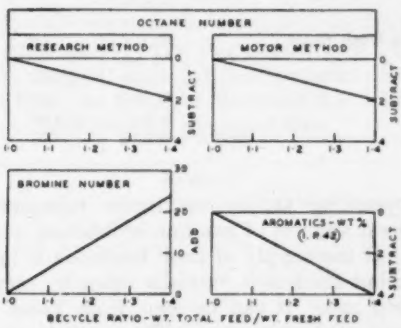


FIG 15

EFFECT OF RECYCLING ON GASOLINE PROPERTIES. CORRECTIONS TO SINGLE PASS DATA

increase of some 5 per cent of the gasoline yield. There is, however, (Fig 15) a general decline in gasoline quality, the aromatics content and octane numbers being lower and the bromine number higher than for single-pass cracking at the same conversion. Neither gas oil nor residue properties are significantly affected by recycling.

It is misleading, of course, to judge the advantages of recycling merely on the basis of percentage recovery of the products at a fixed conversion. For example, in the above case, owing to the lower input of fresh feedstock, the actual production of gasoline falls by recycling, from 31·0 to 26·1 weight

TABLE VII

		Single pass	Recycle
Total feed	% wt	100	125
Fresh feed	„	100	100
Recycle ratio	w/w	—	1·25
Coke	% wt	3·6	3·1
Dry gas	„	7·4	6·5
Total C_4	„	7·5	7·0
Gasoline	„	31·0	32·7
Gas oil	„	18·6	19·8
Residue	„	31·9	30·9

units, although the percentage yield increases. The most satisfactory basis of comparison is again that of gasoline output at fixed coke production and a constant total feed rate, for example, 10,000 lb/hr and 15.000 b.s.d. respectively. On this basis the comparison between single pass and recycle operation is shown in Table VIII.

TABLE VIII

		Single pass		Recycle
Total feed rate	b.s.d.	15,000	12,000	15,000
Fresh feed rate	„	15,000	12,000	12,000
Recycle ratio	v/v	—	—	1·25
430 Conversion (basis fresh feed)	% vol	52	57	60
Coke yield „ „	% wt	5·0	6·25	6·25
Coke production	lb/hr	10,000	10,000	10,000
Gasoline yield	% vol	38·8	40·5	43·1
Gasoline production	b.s.d.	5,820	4,870	5,180
Octane number	motor method	80	80·7	79·8

Hence, when operating at the maximum regeneration and oil-feed capacities the greatest amount of gasoline is obtained when fresh feedstock only is processed. If the supply of fresh feedstock is limited the gasoline production suffers, but the loss is partially offset by recycling to maintain maximum total feed rate; it can be seen, from Table VIII, that this is preferable to increasing the conversion. There is little or no difference in the properties from the single-pass and recycle operations at maximum oil-feed rate, since the loss in quality through recycling is balanced by the gains due to the higher conversion used.

WAX DISTILLATES FROM VARIOUS CRUDES

The preceding data have been confined to a feedstock derived from Field A crude oil. Wax distillates from four Middle East crude oils have been processed in the Sunbury pilot unit with the same catalyst and under identical process conditions, except, of course, space velocity. This latter variable was used to attain the desired feedstock conversion. In order to compare feedstocks from these four fields wax distillates were prepared from each

crude oil; their boiling ranges are sufficiently close to enable a broad comparison to be made (*vide* Table II). The existing differences must, however, be taken into consideration when attempting to draw conclusions from small differences in the following results.

The product yields, basis feed, on cracking each of these wax distillates to 50 per cent conversion are given in Table IX. Apart from the coke and hydrogen sulphide there are no major differences in the yields given by the

TABLE IX

Wax Distillates from Middle East Crudes. Product Yields at 50% Conversion (Pilot Plant)

Feedstock ref.		A.1	B.1	C.1	D.1
Crude source		Field A	Field B	Field C	Field D
Yields (basis feed) :—					
Coke (10% hydrogen)	% wt	3·6	2·6	2·7	3·1
Hydrogen sulphide	% wt	0·65	0·47	1·1	0·45
"	s.c.f/brl	23	17	39	16
Dry gas	% wt	7·4	6·2	6·1	6·5
"	s.c.f/brl	310	250	246	214
Total C_4	% vol	11·5	11·3	11·0	11·8
Gasoline, debutanized	"	37·9	39·3	38·8	37·7
Gas oil	"	18·9	17·0	17·5	19·0
Residue	"	31·1	33·0	32·5	31·0

four feedstocks. Thus, for the gas and liquid products the yields could be quoted as in Table X. These limits can be attributed to experimental error or to the slight differences in the quality of the feedstocks. The coke yields vary over a wider range. The wax distillates B.1 and C.1 give almost the same coke yield, but that from A.1 is 38 per cent greater, and from D.1 20 per cent greater than the value for feedstock B.1. These differences are important, and their significance is discussed later.

TABLE X

On feed		Yield
Dry gas	% wt	6·7 ± 0·7
Total C_4	% vol	11·4 ± 0·4
Gasoline	"	38·5 ± 0·8
Gas oil	"	18·0 ± 1·0
Residue	"	32·0 ± 1·0

The comparative properties of the cracked gasolines, gas oils, and residues from the respective feedstocks are given in Table XI. For all three products the major differences lie in the sulphur contents and in the fact that the wax distillate C.1 gives a gasoline appreciably less volatile and a gas oil with a low Conradson carbon residue, attributable to the slightly higher boiling point of the feedstock. The remaining properties of the products are very similar. The results in Table XII are obtained by expressing the weight per cent sulphur in a product as a percentage of the weight per cent sulphur in the feedstock. Thus, although in general the sulphur content of the product follows that of the feedstock, there is no

TABLE XI

Wax Distillates from Middle East Crudes. Properties of Products at 50% Conversion

Feedstock ref.		A.1	B.1	C.1	D.1
Gasoline (debutanized) :—					
Sp. gr. at 60° F		0·752	0·748	0·753	0·744
Sulphur	% wt	0·15	0·12	0·26	0·11
Bromine No.		108	120	122	99
Aromatic content	% wt	32·5	30	31	34
$D + L$ to 100° C	% vol	50	53	46	53
Octane No. M.M.		80	80·5	78·5	79
,, ,, R.M.		94·5	94·5	93·5	94·5
Gas oil :—					
Sp. gr. at 60° F		0·919	0·929	0·936	0·920
Sulphur	% wt	1·92	2·10	3·61	2·77
Visc at 70° F	cs	5·1	4·9	5·2	5·0
Pour pt	° F	0	0	0	5
Conradson carbon (10% residue)	% wt	0·40	0·30	0·10	0·35
Diesel index		20	15	14	20
Residue :—					
Sp. gr. at 60° F		0·940	0·926	0·954	0·954
Sulphur	% wt	1·9	1·99	3·16	2·73
Visc at 100° F	cs	21·7	25·5	25·5	20·0

direct relation between the two. The outstanding anomaly occurs in the gasoline from wax distillate ex Field D, where the sulphur content is only 5 per cent of that of the feedstock as against a value of 7·6 to 9 for the other three crude oils. It is of interest to note that in all cases the sulphur content of the gas oil and residue are greater than those of the corresponding wax-distillate feedstocks.

TABLE XII

Crude source	Field A	Field B	Field C	Field D
Gasoline	8·5	7·6	9·0	5·1
Gas oil	107	132	125	127
Residue	107	125	109	125

There is also a general similarity in the distribution of bromine and octane numbers in the gasoline ranges pertaining to feedstocks A.1, C.1, and D.1 as shown in Fig 16. Thus, at 55 per cent conversion the bromine number progressively falls as the boiling point of the fraction rises, being *ca* 160 in the 40° to 60° C. t.b.p. fraction and less than 5 in the 180° to 200° C fraction. Over the range 75° to 200° C t.b.p. the bromine numbers of gasolines from feedstock A.1 are some 10 units higher than from feedstocks C.1 and D.1. At this same conversion level the profiles of octane-rating distribution are similar for each feedstock. In the boiling range 75° to 100° C t.b.p. there is a sharp fall in both the motor and research ratings, which is more pronounced in the gasoline from feedstock C.1. As there is no corresponding fall in the bromine number, the general phenomenon is attributable to the absence of benzene.

Throughout the remaining boiling ranges examined, the octane ratings were shown to give no large fluctuations from the mean value, as may be

expected from the steady rise in aromatics concentration and progressive fall in the olefin contents.

The effect of the differences in the carbon yield given by the four feedstocks is emphasized by consideration of the yields for a fixed regenerator capacity. These data are given in Table XIII for a coke-burning rate of 10,000 lb/hr, the feedstock conversion being 50 per cent in all cases. Of

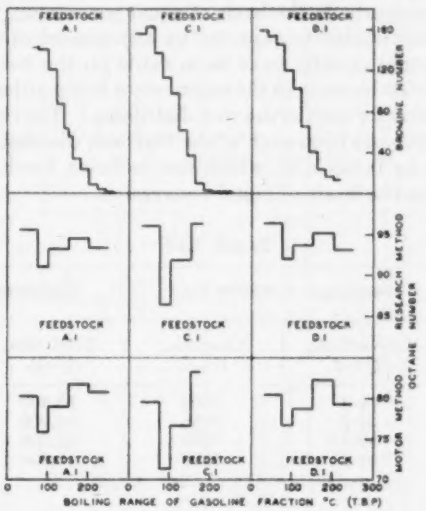


FIG 16

DISTRIBUTION OF BROMINE NUMBER AND OCTANE NUMBERS IN GASOLINE RANGE AT 55% CONVERSION

the four feedstocks the wax distillate derived from Field B crude oil gives the highest gasoline and C_4 productions. Taking the gasoline-production index of this wax distillate as 100, the corresponding values for wax distillates from Fields C, D, and A are 95, 84, and 75 respectively.

TABLE XIII

Wax Distillates from Middle East Crudes. Yields for Given Regenerator Capacity (Large-scale Plant)

Feedstock ref.		A.1	B.1	C.1	D.1
Basis 10,000 *lb/hr coke* :—					
Oil feed rate	b.s.d.	16,300	20,900	20,000	18,300
Hydrogen sulphide	s.c.f.h.	15,600	14,800	32,500	12,200
Dry gas	,,	209,000	218,000	205,000	163,000
Total C_4	b.s.d.	1,870	2,360	2,200	2,160
Gasoline (debutanized)	,,	6,180	8,210	7,760	6,900
Gas oil	,,	3,080	3,550	3,500	3,500
Residue	,,	5,070	6,900	6,500	5,670

The broad conclusions which may be reached with regard to these four crude oils is that there is little to choose between them on the basis of

gasoline yield per barrel of feedstock, but that the same daily productions of gasoline at equal feedstock conversions could not be achieved in a unit where the regenerator capacity was the limiting factor. Further, the qualities of the cracked gasolines are very similar, except that the high sulphur content of the C.1 feedstock gives a correspondingly high value for the gasoline fraction.

The above comparison of the wax distillates from these four Middle East fields has been made on the basis of equal conversion, viz., 50 per cent, with the regenerator loaded to capacity by adjustment of the oil feed-rate. The comparison could equally have been made on the basis of equal feed-rates, the rate of coke-burning in the regenerator being adjusted by adopting a different conversion for each of the wax distillates. The respective gasoline productions on this basis from each of the four wax distillates, A.1, B.1, C.1, and D.1 are given in Table XIV, which also includes, for direct comparison, the productions on the basis of equal conversion.

TABLE XIV

Feedstock	Feed-rate = 20,000 b.s.d		Conversion = 50% vol	
	Conversion, % vol	Gasoline, b.s.d.	Feed-rate, b.s.d.	Gasoline, b.s.d.
A.1	44·9	7100	16,300	6180
B.1	51·2	7950	20,900	8210
C.1	50·0	7760	20,000	7760
D.1	47·2	7320	18,300	6900

Thus, on the basis of equal feed-rate, the gasoline production differential between the most and least favourable feedstocks (A.1 and B.1) is lessened, but, of course, this improvement is at the expense of increasing the problem of disposing the cracked material boiling above the gasoline.

EFFECT OF FEED BOILING RANGE

In order to investigate the effect of the feedstock boiling range on the cracking reaction three consecutive 12 per cent volume fractions in the wax-distillate range were prepared from crude oil ex Field A. In addition, the two lighter fractions and the two heavier fractions were blended to give two further feedstocks each representing 24 per cent volume on crude oil. The properties of these feedstocks are detailed in Table II, the basic fractions being feedstocks A.2, A.3, and A.4, and the two blends being designated A.2/3 and A.3/4. Each of these feedstocks was processed in the pilot unit with the same catalyst and over a wide range of conversion by adjusting the space velocity, all other process conditions being practically identical. The results of such work are given in Tables XV, XVI, and XVII by means of data at conversion levels of 45 and 55 per cent, respectively, the values being interpolated from the plot of the yield or property against conversion. The quantity of gasoline per unit of feed increases appreciably as the boiling point increases, whilst the respective quantities of dry gas

TABLE XV

Effect of Feed Boiling Range. Product Yield Distribution (Pilot Plant)

Conversion		45% vol					55% vol				
Feedstock ref.		A.2	A.3	A.4	A.2/3	A.3/4	A.2	A.3	A.4	A.2/3	A.3/4
Boiling range (T.B.P.)	°C	305–381	381–467	467–610	305–467	381–610	305–381	381–467	467–610	305–467	381–610
Yields (basis feed) :—											
Coke (10% hydrogen)	% wt	2·12	2·39	3·47	2·00	2·72	3·98	3·45	4·48	3·48	3·84
Hydrogen sulphide	,,	0·46	0·59	0·74	0·51	0·64	0·52	0·66	0·83	0·58	0·73
Dry gas	,,	6·85	5·45	4·8	6·9	5·7	9·9	7·6	7·1	9·2	7·5
Dry gas	s.c.f/brl	275	241	258	293	266	413	323	345	408	340
Total C_4	% vol	13·2	9·7	5·4	11·1	7·8	16·5	13·2	9·1	14·7	11·6
Gasoline (debutanized)	,,	29·6	36·1	40·4	33·0	37·3	32·2	40·8	44·8	36·0	42·4
Gas oil	,,	37·2	14·3	17·1	30·9	15·5	30·8	14·1	17·1	26·2	15·3
Residue	,,	17·9	40·7	37·8	24·0	39·7	13·3	30·9	27·9	19·1	29·8

TABLE XVII

Effect of Feed Boiling Range. Yields for Given Regenerator Capacity (Large-scale Unit)

Conversion		45% vol					55% vol				
Feedstock ref.		A.2	A.3	A.4	A.2/3	A.3/4	A.2	A.3	A.4	A.2/3	A.3/4
Boiling range (T.B.P.)	°C	305–381	381–467	467–610	305–467	381–610	305–381	381–467	467–610	305–467	381–610
Basis 10,000 *lb coke/hr* :—											
Oil feed-rate	b.s.d.	25,200	22,200	16,200	25,600	19,800	15,700	16,900	13,200	17,100	15,300
Hydrogen sulphide	s.c.f.h.	16,800	19,400	18,200	19,200	19,000	11,800	16,200	17,100	14,300	16,600
Dry gas	,,	289,000	223,000	174,000	313,000	219,000	270,000	227,000	190,000	291,000	217,000
Total C_4	b.s.d.	3,330	2,150	875	2,840	1,540	2,590	2,230	1,200	2,510	1,770
Gasoline (debutanized)	,,	7,460	8,010	6,540	8,450	7,390	5,060	6,900	5,910	6,160	6,490
Gas oil	,,	9,370	3,170	2,770	7,910	3,070	4,840	2,380	2,260	4,480	2,340
Residue	,,	4,510	9,040	6,120	6,140	7,860	2,090	5,220	3,680	3,270	4,560

TABLE XVI

Effect of Feed Boiling Range. Properties of Products

Conversion		45% vol					55% vol				
Feedstock ref.		A.2	A.3	A.4	A.2/3	A.3/4	A.2	A.3	A.4	A.2/3	A.3/4
Boiling range (T.B.P.)	°C	305–381	381–467	467–610	305–467	381–610	305–381	381–467	467–610	305–467	381–610
Gasoline (debutanized) :—											
Sp. gr. at 60° F		0·760	0·749	0·755	0·754	0·753	0·757	0·746	0·752	0·751	0·749
Sulphur	% wt	0·14	0·14	0·19	0·15	0·17	0·12	0·12	0·16	0·13	0·16
Bromine No.		79	106	124	100	130	67	106	122	84	118
Aromatic content	% wt	43	30	26	38	27	46	32	27	40	31
D + L to 100° C	% vol	48	50	34	50	40	49	52	41	53	50
Octane No. M.M.		81·5	79·5	78·5	80·5	78·5	82	80	79	81·5	79·5
„ R.M.		95	95·5	93·5	94	93·5	96·5	96	93·5	95	94·5
Gas oil :—											
Sp. gr. at 60° F		0·874	0·939	0·916	0·885	0·921	0·882	0·949	0·925	0·899	0·937
Sulphur	% wt	1·23	2·25	1·76	1·42	2·02	1·38	2·41	1·95	1·53	2·22
Visc at 70° F	cs	4·86	4·86	4·45	4·93	4·64	4·66	4·66	4·40	4·75	4·59
Pour point	°F	10	−10	< −30	5	−20	10	−10	< −30	5	−20
Conr carbon (10% residue)	% wt	0·27	0·6	0·8	0·35	0·7	0·25	0·6	0·8	0·35	0·7
Diesel index		43	10	16	37	13	39	7	10	31	9
Residue :—											
Sp. gr. at 60° F		0·913	0·920	0·970	0·918	0·943	0·939	0·934	0·998	0·941	0·962
Sulphur	% wt	1·71	1·63	2·33	1·68	2·03	2·03	1·83	2·60	1·97	2·21
Visc at 100° F	cs	11·6	20·7	53	15·8	36	13·0	20·7	54	17·2	33

(weight basis) and total C_4 decrease steadily, the proportional change being greatest in the case of the C_4 fraction. That is, the overall volatility of the product decreases as the feedstock becomes heavier. These are, of course, advantages where the object is motor gasoline production, but, unfortunately, they are offset by increasing coke production as the boiling point of the feedstock is raised. The difference in coke yields between the two lighter feedstocks is not very serious, in fact, at 55 per cent conversion, the A.3 feedstock gives a lower coke yield than the lighter A.2 feedstock. There is, however, an appreciable rise in the case of the A.4 feedstock, whose mid-boiling point is 538° C. The relative yields of dry gas are of interest in that the heavy A.4 feedstock gives a comparatively greater gas-volume yield than would be expected from the weight yields. This means that the proportion of hydrogen and light hydrocarbons in the gas from this feedstock is increased. Although this may be an inherent property of the feedstock, it cannot be overlooked that high hydrogen and methane production are characteristic of contamination of the catalyst by feedstock impurities. For a given feedstock the yield of these components may, in fact, be taken as a measure of catalyst contamination. Such contamination also increases the coke production, which again is in line with the results from A.4. It may well be, therefore, that the increase in coke with increasing feed gravity is largely due to the increase in such feedstock contaminants as metals, nitrogen, or sulphur. Of these contaminants the metallic ones have probably the largest permanent effect on the gas- and carbon-producing tendencies of the catalyst. For this reason it is important to reduce as far as possible the carry-over of heavy material during the production of the wax-distillate feedstock by vacuum distillation. An increase in feedstock availability at the expense of clean fractionation could well lead to a decrease in the ultimate cracked gasoline production. The probable behaviour of a " clean " heavy feedstock is an interesting speculation.

Although the yield of gasoline increases with feedstock gravity, the quality of the gasoline deteriorates. Proceeding, at 45 per cent conversion, from the lightest feed, A.2, to the heaviest, A.4, the bromine number increases from 79 to 124, the aromatic content decreases from 43 to 26 per cent, the sulphur content increases from 0·14 to 0·19, and the octane number falls from 81·5 to 78·5 (Table XVI). The behaviour at 55 per cent conversion is parallel. The volatility shows a marked decrease in the case of the gasoline from A.4, the " $D + L$ " to 100° C being only 34 per cent volume at 45 per cent conversion, as against 48 to 50 per cent volume for the two lighter feedstocks. In considering the effect of feedstock on the properties of the cracked gas oils and residues, the lightest, A.2, must be omitted, since it contains an appreciable quantity of material boiling below the cracked-gas-oil cut point of 635° F. This accounts for the abnormally high diesel index of the cracked gas oil from this feedstock. Omitting the results on A.2, it is seen that the heaviest feedstock, A.4, gives a gas oil of lower gravity, viscosity, pour point, and sulphur content, but of higher diesel index and carbon residue. In the case of the cracked residue the gravity, sulphur content, and viscosity are substantially greater with the heaviest feedstock. The reversal in the trend of the sulphur contents of the cracked gas oil and residue, respectively, shows that the sulphur distribution in the products is a function not only of the sulphur content of the feedstock but also of the

nature of the sulphur compounds present. An examination of Tables XV and XVI shows that, except for coke and dry gas *volume*, the yields and properties of the cracked products from the blended feedstocks, A.2/3 and A.3/4, are almost the mean of the values for the blend components. That is, there are no anomalies on mixing the feedstocks. This bears out the general experience that for most purposes feedstocks from the same crude oil may be characterized by their 50 per cent volume temperature. Hence, in discussing the effect of feed boiling range, the arguments can be simplified by considering only the three consecutive fractions, A.2, A.3, and A.4.

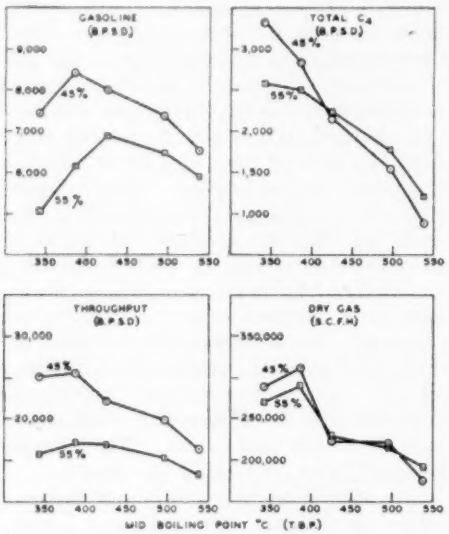


FIG 17

EFFECT OF FEED BOILING RANGE. THROUGHPUT AND YIELDS FOR 10,000 LB/HOUR COKE BURNING CAPACITY

The effect of increasing feedstock boiling range on the product yields (basis feed) is best seen by placing the data of Table XV on a comparative basis. In Table XVIII the yields of each product are pro-rated to an index value of 100 for the lightest feedstock, A.2. The data for the gas oil and residue

TABLE XVIII

Feedstock	45% Conversion			55% Conversion		
	A.2	A.3	A.4	A.2	A.3	A.4
Coke . . . wt	100	113	164	100	87	130
Dry gas . . . ,,	100	78	70	100	77	72
Dry gas . . gas vol.	100	88	94	100	78	84
Total C_4 . . liq. vol.	100	73	41	100	80	55
Gasoline . . ,,	100	122	136	100	127	139

have been omitted since, first, at a given conversion the total material above gasoline is, by definition, a constant, and secondly, the ratio of gas oil to residue is affected by the amount of material in the gas-oil boiling range present in the feedstock.

As in previous comparisons the effect of feedstock boiling range on productions from a commercial unit is best seen by considering a fixed coke-burning capacity of 10,000 lb/hr. These data are given in Table XVII and graphically in Fig 17, for conversion levels of 45 and 55 per cent, respectively. Taking into account the practical difficulties associated with the determination of true and accurate coke yields the broad conclusion may be reached that, for this particular crude oil, feedstocks of approximately 400° C mid-boiling point are the most advantageous for motor gasoline production. The second, but important feature, which is shown by Fig 17 is that the daily production of dry gas and total C_4 fraction decreases steadily as the feedstock gravity increases. If, therefore, the gas-compression and stabilization equipment is designed for a light feedstock, such as gas oil, there will be sufficient flexibility to deal with any other feedstock.

A systematic study of the above nature is only available for feedstocks derived from crude oil ex Field A. It was shown above that the results obtained with equivalent boiling-range feedstocks from four Middle East crude oils were essentially the same. It is probable, therefore, that the general conclusions reached with regard to the effect of boiling range with respect to Field A feedstocks are also applicable to the feedstocks derived from other crude oils. The greatest uncertainty lies in variation of the extent and nature of the contaminants in the feedstocks. These contaminants have, as previously discussed, a marked effect on the coke-producing tendency of the catalyst and, for a fixed coke-burning capacity, this factor has an over-riding effect on the gasoline production.

Sulphur Distribution

With wax-distillate feedstocks, in which the sulphur contents are of the order of 2 per cent weight, the behaviour of the sulphur compounds and their distribution in the cracked products is an important and interesting feature of the cracking reaction. Some information on this subject has been given and briefly discussed in previous sections of this paper. The purpose of this section is to present a generalized correlation of the sulphur distribution with respect to heavy feedstocks from Middle East crude oils.

The variation, with feedstock conversion, of the percentage sulphur contents of the cracked products show regular trends as indicated in Fig 18, the data being with reference to a normal wax distillate (A.1) from Field A crude oil. The percentage of sulphur in the gas oil and residue increases almost linearly with conversion, and that of the dry gas decreases. Since the boiling range of the residue is effectively the same as the feedstock, it may be inferred, from the rise in residue sulphur content with conversion, that at least some of the sulphur compounds in the feedstock are more refractory than the hydrocarbons. The proportion in the debutanized gasoline fraction decreases at a decreasing rate up to about 60 per cent conversion, and then shows a reversal with an ill-defined minimum at 70 per cent conversion. Whilst being of practical value, the data of Fig 18

are somewhat misleading from the point of view of the behaviour of the feedstock sulphur compounds, since they are complicated by the variations in product yields with conversion. For this reason, the sulphur distribution

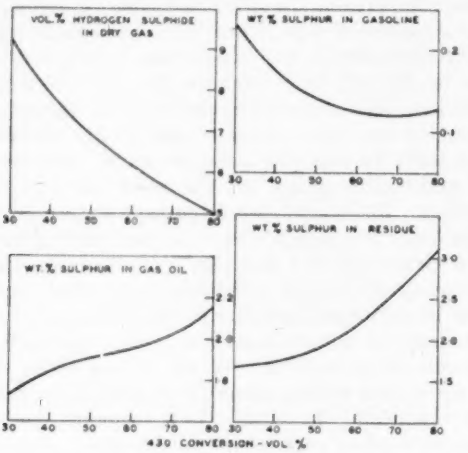


FIG 18

EFFECT OF CONVERSION ON SULPHUR CONTENTS OF PRODUCTS

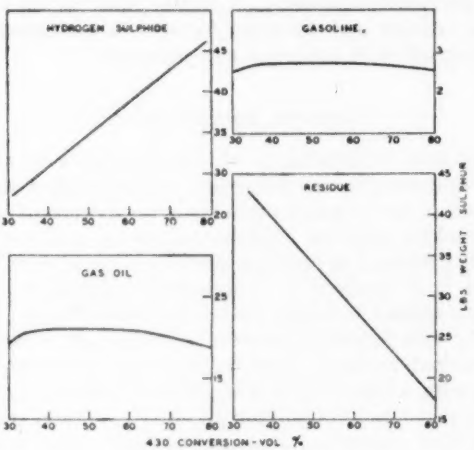


FIG 19

EFFECT OF CONVERSION ON TOTAL SULPHUR IN PRODUCTS (BASIS 100 LB OF FEED SULPHUR)

is given in Fig 19 as the percentage of feed sulphur in each of the four broad product fractions, the units being total pounds of sulphur in the fraction basis 100 lb of feed sulphur. The main feature of these data is that the total

amount of sulphur in the gasoline and gas-oil fractions remains almost constant, the variation in percentage content given in Fig 18 being due to variation in yield with conversion. The total weight of sulphur in the residue decreases linearly with conversion, and this is reflected by a parallel increase in the weight of hydrogen sulphide produced. Over the range 30 to 80 per cent the net effect of increasing conversion is, therefore, to give increasing removal of the feedstock sulphur compounds in the form of hydrogen sulphide. The extent of this desulphurization is appreciable, since, for example, at 55 per cent conversion 37 per cent by weight of the feedstock sulphur is removed as hydrogen sulphide. No firm explanation has been found for the constancy of the total weight of sulphur in the gasoline and gas oil, the most probable being that the rate of re-cracking of the sulphur components is effectively equal to their rate of formation.

The sulphur distribution in the products varies with the crude oil from which the wax-distillate feedstock is derived. This is shown by the data of Table IX, which give, on the basis of 100 lb of feed sulphur, the relative weights of sulphur in the products from equivalent wax distillates obtained from four Middle East crude oils. The differences are not very great in the heavier products, but those for the gasoline and dry gas are appreciable. It is interesting to note that no sulphur compounds were present in the cracked C_4 fraction, although traces have been found in the commercial product.

In addition to sulphur distributions on the broad product fractions, the sulphur distributions in the stabilized liquid products from typical wax distillates derived from the crude oils of Fields A, C, and D, respectively, have been examined in detail. The results are given in Fig 20, on the basis of the sulphur content and on the basis of the percentage of feed sulphur in the fraction. The data for the three crude oils are comparable, since the feedstocks have approximately the same boiling range, and the conversion is 55 per cent in each case. The main feature is that the general

TABLE XIX

Sulphur Distribution. Variation with Crude Source (50% Conversion)

Feedstock ref.		A.1	B.1	C.1	D.1
Sulphur	wt %	1·77	1·59	2·90	2·17
Sulphur in Products, Basis 100 lb feed sulphur :—					
Dry gas	lb	35	—	—	20
Total C_4	,,	Nil	Nil	—	Nil
Gasoline	,,	2·7	2·3	2·9	1·6
Gas oil	,,	21	23	22	25
Residue	,,	34	42	36	41
Coke (by difference)	,,	7·3	—	—	12·4

form of the sulphur distribution is the same in all three products, the differences being quantitative rather than qualitative. In all cases the sulphur content is less than 0·1 per cent weight for fractions below a true boiling point of 100° C and lies between 0·1 and 0·5 per cent weight in the 100° to 200° C range. Above 200° C the sulphur content shows a sharp consistent rise with a fairly well-defined peak in the 260° to 280° C fraction, which, in the case of feedstock C.1, has a sulphur content of 5·5 per cent

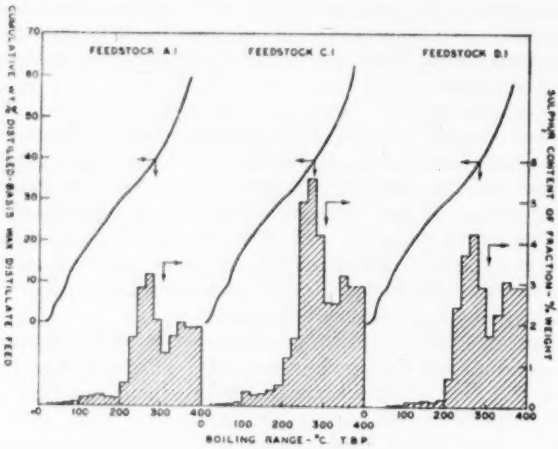

FEEDSTOCK A.I
FEEDSTOCK C.I
FEEDSTOCK D.I
CUMULATIVE WT.% DISTILLED-BASIS WAX DISTILLATE FEED
SULPHUR CONTENT OF FRACTION - % WEIGHT
BOILING RANGE - °C. T.B.P.

FIG 20

SULPHUR AND YIELD DISTRIBUTION IN CRACKED LIQUID PRODUCT AT 55% CONVERSION

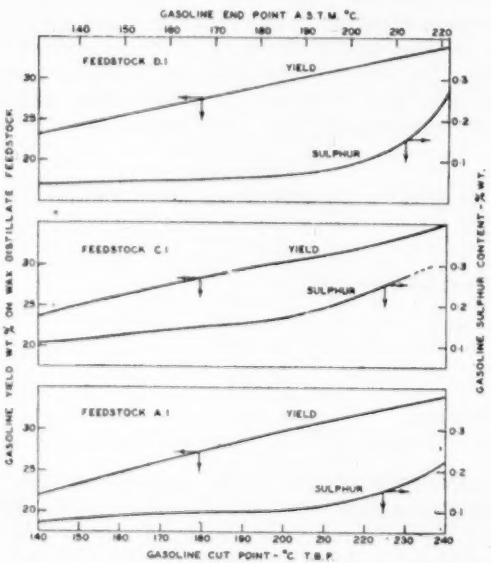


FIG 21

VARIATION OF SULPHUR CONTENT AND YIELD OF GASOLINES WITH CUT POINT AND END POINT 55% CONVERSION

by weight. Since the sulphur-distribution curve (Fig 20) rises sharply after 200° C small changes in the normal cut point of the gasoline have an appreciable effect on its sulphur content. This effect is given in Fig 21 as the weight per cent sulphur to any cut-point or end-point (ASTM).

Acknowledgment

The correlations presented in this paper are the results of the combined efforts of the Development and Analytical Staff at the Sunbury Research Station, and thanks are due to the Chairman of the Anglo-Iranian Oil Co. Ltd. for permission to publish this paper.

NOMENCLATURE

Conversion. 100 minus the volume per cent of the product boiling above 430° F t.b.p. (fourteen-plate batch distillation at 7 to 1 reflux ratio).

Space velocity. Weight of oil feed per hour per unit weight of catalyst in the reaction zone.

Catalyst : oil Ratio. Weight of catalyst circulated divided by the weight of oil fed to the reactor over the same time interval.

Recycle ratio. Ratio of weights of total to fresh feed pumped to the reactor in unit time.

Coke. The hydrogen content of the coke is assumed to be 10 per cent by weight and the coke yield is taken as 1·11 times the estimated carbon yield.

Dry gas. Hydrogen plus all hydrocarbon gases up to and including the C_3 hydrocarbons (H_2S excluded).

Gasoline. Debutanized material distilling to an overhead temperature of 430° F in a fourteen-plate batch distillation at 7 to 1 reflux ratio.

Gas oil. Material boiling between overhead cut points of 430° and 635° F in the same distillation.

Residue. Material remaining after removal of the above products.

Heavy cycle oil. Material boiling above the gas oil but below an 8 per cent weight residue (representing the main fractionator-bottoms product on a large unit). The heavy cycle oil is used as a recycle stock in the Recycling Operations.

Catalyst activity. Volume per cent of distillate plus loss to 204·5° C (ASTM) in the liquid products from a test run under standard conditions (850° F, 0·6 v/v/hr, 2-hr cracking cycle) in the standard 200-cc pelleted-bed testing unit. Result expressed as Jersey "$D + L$" units.

Carbon-producing factor. Ratio of the amounts of carbon produced at a given conversion by the test sample and a steam-deactivated reference sample, during the standard pelleted-bed activity test.

Gas-producing factor. Ratio of the volume of gas produced at a given conversion by the test sample and a steam-deactivated reference sample during the standard pelleted-bed activity test.

OBITUARY

JAMES TAYLOR GUTHRIE

JAMES TAYLOR GUTHRIE was born in 1884 and was trained as an electrical engineer, serving the early part of his career in Glasgow.

At the age of twenty-seven he joined the Anglo-Persian Oil Co. and took up a post in the Abadan refinery as an assistant electrical engineer.

When he joined the Abadan refinery staff in 1911 the refinery had not yet been commissioned, and he was one of those early pioneers who were responsible for the gradual expansion of a refinery which subsequently made a major contribution to the war effort of the first world war.

The experience thus gained was to stand him in good stead in later years, and he became assistant superintendent engineer in 1921 and works superintendent in 1927.

In 1930 he was appointed works manager, a post which he held until his retirement from Persia in 1937. During that period he had been closely associated with the expansion and modernization of a refinery which had grown to a capacity of 10,000,000 tons/year.

He will be remembered with affection by the many young men who became members of his staff, not only for his administrative ability and the guidance and encouragement that he gave to new arrivals, but also outside working hours for the hospitality which he and his wife showed to all comers.

He was an enthusiastic supporter of all sports and social activities, a particularly keen golfer, and a hard worker on the Golf Club Committee.

After his retirement from Persia he settled down in Edinburgh, but, after the outbreak of war, offered his services to A.I.O.C. and took up a position as manager of the Packed Oil Manufacturing Plant at Llandarcy, where he stayed until 1945, when he finally retired.

His later years showed no loss of that vigour and energy which he had displayed during his many years abroad, and his sudden death, when he was apparently in the best of health, came as a great shock to his many friends and colleagues.

J. T. Guthrie joined the Institute of Petroleum as a Member in 1929, and was transferred to Fellowship in 1939. When the Scottish Branch was formed in 1938 he was an active supporter. He served Branch Committee from its inception, and was its first and only vice-chairman.

H. W. R.

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Oilfield Exploration and Exploitation

Geology

2815. The origin of petroleum. F. Morton. *I.P. Review*, 1952, **6**, 161; 221.—Although a great deal of investigation into oil has been carried out, there is still very little known with certainty about its origin; chiefly because oil is not necessarily found in the same rocks as it was formed. The theories of occurrence which have been put forward during the last fifty years are briefly summarized. Particular reference is made to the "deep burial theory," which is based upon the view that oil is formed at a great depth, and to the "shallow depth of burial theory." The assumptions necessary for each of these theories are enumerated, and their relative merits discussed.

Geological investigation into this problem has been conducted along three main lines. The first was to search for evidence of deposits of the black shale type in all sedimentary rocks near to a known oilfield. The second was to determine the organic content of modern deposits, and to study the microbiology and organic content of the offshore ocean deposits. The third approach was to study the relation between the composition of crude oil and stratigraphy. All these studies were linked with day-to-day field observations of geologists. Results obtained from all these investigations are given and discussed. R. H.

2816. (Padua) Study centre for petrology and geology. A. Bianchi and G. dal Piaz. *Ric. Sci*, 1952, **22**, 1379–89.—An account is given of the activities for the year 1951 of the Study Centre for petrology and geology at Padua University.

These activities are related to the scheme of research carried out over a five-year period, during which there appeared seventy-four original publications by twenty-four workers. The programme of research for the next five years is foreshadowed. E. H.

2817. The folded Appalachians. H. W. Straley. *Proc. 3rd World Petrol. Congr.*, 1951, **1**, 36–40.—The possibility is reviewed of the presence of oil accumulation in regions of highly faulted and metamorphosed rocks.

The folded Appalachians consist of a series of shingle blocks separated by thrust faults. If, however, the basement rocks of this region are only slightly disturbed, as has been suggested, it is possible that oil and/or natural gas may be found in structures beneath the thrust sheet zone.

Accompanying the paper is a figure showing how deformation above an unaffected basement might be produced. G. S. S.

2818. Geological aspects of abnormal reservoir pressures in the Gulf Coast region of Louisiana, U.S.A. G. Dickinson. *Proc. 3rd World Petrol. Congr.*, 1951, **1**, 1–17.—An attempt is made to link geological factors with occurrences of abnormal pressure. High pressures result by compaction of shales under weight of the overburden, which is equivalent to approx 1 p.s.i/ft depth. Knowledge of the depth at which the main facies-change takes place is therefore probably an important factor in estimating the depth at which abnormal pressures may be met in exploration wells.

A detailed study was made of well-logs known to have encountered abnormal pressure and also neighbouring wells with normal pressure. Stratigraphic sections drawn through a series of typical wells across the West, East, and Delta regions of the area show that abnormal pressure commonly occurs only below the base of a main sand formation in or below a major shaly series.

In some other areas faulting has undoubtedly given rise to very high subsurface pressures, but in the Gulf Coast region itself such movements appear to be absent, except perhaps locally around salt domes. Many sections accompany the paper. G. S. S.

2819. Distribution of oilfields in the western part of the United States. G. B. Moody. *Proc. 3rd World Petrol. Congr.*, 1951, **1**, 18–23.—The territory covered by this paper includes the states of Washington, Oregon, Idaho, Utah, Nevada, Arizona, and

California. Each state is discussed separately, reference being made to the number of wells drilled, production figures, and other statistical data.

The most dominant state is California. Here the chief oilfields occur in the San Joaquin Valley, Los Angeles Basin, the Coastal Region, and the Central Coast Ranges. The proved productive area of all the oilfields in California is about 287,000 acres with an average yield of more than 30,000 brl per proved acre. G. S. S.

2820. Oil and gas development in Alberta. O. B. Hopkins and E. W. Shaw. *Proc. 3rd World Petrol. Congr.*, 1951, **1**, 24–35.—Describes the physiography and, in particular, the stratigraphy of Alberta. The different grades of oil and the chief types of oil and gas occurrences are summarized, special attention being given to accumulations in limestone and dolomite reefs, in biostroms and shoal reefs, and in sands.

A review is made of the reserves so far proved in the main fields, such as Leduc, Redwater, and Golden Spike. Leduc was discovered in 1947, and has now become one of the most active and extensive fields in the world. In 1950 a total of about 225 exploratory wells were drilled, and to-day Leduc has reserves of some 250,000,000 brl. It produces from two main horizons and covers an area of over 40 sq. miles.

In general, Alberta's oil reserves have increased from 100,000,000 brl in 1946 to considerably in excess of 1 billion brl to date. G. S. S.

2821. Relationships between crude oil composition and stratigraphy in the Forest Reserve field of south west Trinidad. K. W. Barr, F. Morton, A. R. Richards, and R. O. Young. *Proc. 3rd World Petrol. Congr.*, 1951, **1**, 345–58.—This is a review of the results of a survey, with particular reference to the problem of the origin of oils in the Miocene Sands of the Forest Reserve field.

Oil indications range from the oldest known beds to the youngest, though oil impregnations in the Pliocene probably arise from migrant oil associated with the Los Bajos and other faults, and with sedimentary vulcanism.

The underlying Miocene (from which most of Trinidad's production has been obtained) shows widespread impregnation both in the upper or Forest Sands and in the lower or Cruise Sands. A brief account is given of the geology of the reservoir rocks from type localities.

Within sands of the same age and in the same district, marked variations occur in crude oil properties, while oil from sands of different ages in the same district vary in hydrocarbon distribution.

Migration from deep-seated levels by major faulting does not appear to have occurred; local migration can be deduced near the Los Bajos fault.

Oils in general are believed to have been derived from clayey source beds, and variations in crude oil to differences in source material and environment. G. S. S.

2822. Geological significance of the distribution of the Mexican oilfields. M. Alvarez, Jr. *Proc. 3rd World Petrol. Congr.*, 1951, **1**, 73–85.—The origin and nature of the Gulf Coast geosyncline in the southern U.S.A. are discussed, and a brief review is given of the main features of the three oil provinces—the Burgos Basin, Tampico–Tuxpan, and the Isthmus fields.

In the Burgos Basin the only field sufficiently developed is the Reynosa. This is a flat, elongated high, practically a terrace, superimposed on a homocline. The main oil-producing sand is the Reynosa Sand, which is similar to the Michigan Stray Sand of the Austin field in the Michigan Basin.

The Tampico–Tuxpan fields constitute the most important petroleum province of Mexico. They have produced over 90% of the Mexican petroleum, and the reserves represent a very high percentage of the total reserves in Mexico. The oil occurs in limestone of Middle and Lower Cretaceous age.

Of the Isthmus fields, the most important is El Plan which produces from Miocene overlying a salt dome. Until recently, only the north and northeast flank of the dome had been developed in the two upper formations; now, however, the two lower formations on both the northern and southwest flanks are being developed. G. S. S.

2823. The Cretaceous limestone producing areas of the Mara and Maracaibo district—Venezuela. J. E. Smith. *Proc. 3rd World Petrol. Congr.*, 1951, **1**, 56–72.—In these areas of Cretaceous limestone production, a description is given of the two most important

fields—La Paz and Mara. La Paz is a sharply folded and faulted anticlinal structure. Mara is a similar structure, but is separated from La Paz by a shallow saddle of non-productive limestone. The formations in both areas belong to the pre-Cretaceous basement, the Cretaceous, Paleocene, and the Tertiary. The general stratigraphy and characteristics of the limestones (Colon, La Luna, and Cogollo) are reviewed.

Production may come from any part of a 1800-ft section, and is essentially due to the presence of extensive fracturing and fissure systems.

A summary of various drilling methods is given, reference being made to difficulties encountered due to caving shales and consequent loss of circulation in the limestone. The problem of minimizing such losses during drilling is discussed. At present, five well-logging methods are available and, from the point of view of geological correlation, the electric log is the most satisfactory. But, apart from this, no individual logging method has been found effective for obtaining reservoir data. G. S. S.

2824. Fundamental geological characteristics of the Venezuelan oil basins. C. G. de Juana and L. P. Rodriguez. *Proc. 3rd World Petrol. Congr.*, 1951, **1**, 41–55.—The primary character of the Venezuelan sedimentary basins in relation to the genesis and control of petroleum accumulation is reviewed. The possibilities of finding oil in Venezuela are restricted to the northern half of the country, which includes the basins of Maracaibo, Falcon, Maturin, and Barinas-Apure.

The stratigraphy of the petroliferous regions in these basins is fully described, and reference is made to the origin, environment, etc., of the oil.

In addition to stratigraphic correlation charts and sections, the paper contains a full and detailed table of the summary of the Venezuelan oilfields by oil basins.

G. S. S.

2825. Relations between the chemical nature of seepages and their geological origin in a sedimentary basin—Bassin de Manosque–Forcalquier. M. Louis and R. Gageonnet. *Proc. 3rd World Petrol. Congr.*, 1951, **1**, 390–400. (In French.)—A study of the sedimentation of the Tertiary lagunolacustrine deposits of the Manosque–Forcalquier Basin, and the detailed chemical analyses of many seepages, show that there exists a parental relationship between the various free bitumens and that they originate from two types of pyro-bituminous rocks of Oligocene age.

The organic material preserved originally in these deposits has yielded bitumens with properties which differ fundamentally from those of normal petroleum in their high sap. val., high fusion point, and richness in carbenes, which indicate a tendency towards asphaltites or associated substances. Another important character is the high sulphur content of both bitumens and pyrobituminous rocks; it is possible this originated at the time of deposition and before the migration of the free bitumens.

G. S. S.

2826. The geology of Aquitaine and its oil possibilities. Y. Gubler, J. Cuvillier, E. G. Bonnard, P. Maugis, F. Michel, and V. Perebaskine. *Proc. 3rd World Petrol. Congr.*, 1951, **1**, 296–314. (In French.)—The principal palæogeographic and orogenic phases of Aquitaine are discussed with a view to interpreting the origin, migration, and accumulation of oil. Stress is laid on the importance of the interplay of large masses of the Hercynian basement in the evolution of later structural phases. Emphasis is also given to the important role played by plastic Triassic sediments which were responsible for the marked character of most of the structures.

Many sections and maps (stratigraphic and tectonic) are given, and these are accompanied by full and detailed explanations. G. S. S.

2827. Oil possibilities of Sicily and the Adriatic zone of the Maiella (Central Apennines) in relation to the general tectonic structure of Italy. E. Beneo. *Proc. 3rd World Petrol. Congr.*, 1951, **1**, 236–9. (In French.)—Italy and Sicily consist mainly of two structural units: an allochthon composed of the plastic Argille Scagliose and a rigid autochthon which is dominantly calcareous and Cretaceous to Miocene in age. The geographical distribution of the Argille Scagliose and the outcrops of the autochthon are given on a sketch map.

In the autochthonous areas of Ragusa and the eastern flank of the Monte Maiella, two rich asphaltic deposits are being worked, and it is thought that beneath the allochthonous cover elsewhere, promising oil deposits will be found. G. S. S.

2828. Jurassic troughs and oil deposits in Northwest Germany. A. Roll. *Proc. 3rd World Petrol. Congr.*, 1951, **1**, 329–34.—Present geological knowledge of the northwest German basin now enables its history and tectonics to be generally determined. The basin is divided into a number of clearly defined units, and it is becoming possible to recognize the connexion between oil shows or fields and some of these subdivisions. Two main blocks can be separated—the "Niedersaechsich Block" and the "Pompeckj Block." In addition to the known troughs of the Jurassic, new troughs should be found below the thick cover of the Cretaceous and Tertiary, since the oil appears to occur in the Jurassic sediments.

The oil-containing trough of Broistedt–Wittengen has an average thickness of about 1000 m at its edges, while its axis may extend to 3000 m. A definite connexion appears to exist between this trough and the adjoining structures, and may even reach as far as Hamburg. This inquiry forms the most important object of exploration in Northwest Germany. G. S. S.

2829. The genesis of oil deposits in the Emsland area (Germany) and their phases of development. H. D. E. Loegters. *Proc. 3rd World Petrol. Congr.*, 1951, **1**, 335–44.—The Emsland oilfields are believed to have originated from one source. The crudes show many uniform characteristics, indicating that they also came from the same source bed, though differing in many respects chemically.

The various types of oils bear a clear relationship to the geological development of the corresponding pools, and can be classified as: (i) "Primary Oil" in the Portland and Wealden beds of the basin, as at Quakenbrueck; (ii) oil in marginal deposits (Wealden and Valanginian), which has migrated from the original basin into the reservoirs, and (iii) "Secondary Oil," which has left these margins in order to migrate again. Accumulation then occurred in new structural highs on anticlines folded at the end of the Cretaceous (*e.g.*, Georgsdorf).

The chemical character of the various types is related to the distance of migration: the farther the migration from the source bed to the present reservoirs, the greater the chemical alteration of the oil. During migration, therefore, the oil must have been in permanent contact with sediments and their formation-water. Thus, varying influences, such as oxidation, have altered the oil. In addition, absorption, bacterial, and radioactive influences may also have played an important part in this connexion. A table is given showing the relations between the chemical composition of the crudes and the length of their migration. G. S. S.

2830. Oil, natural gas, and asphalts of the Adriatic geosyncline. G. Ineichen. *Proc. 3rd World Petrol. Congr.*, 1951, **1**, 199–219. (In French.)—Various theories are put forward to explain the tectonics of the Adriatic geosyncline and their importance respecting oil recoveries and prospects, particularly of the Neogene basins.

A number of brief summaries follow regarding productive fields, the principal gas, asphalt, and bitumen mines, and regions where exploration holes have been drilled. Results are given, and a number of sections illustrating many of the regions accompany the paper. G. S. S.

2831. Gas and oil in the Po plain. D. Jaboli. *Proc. 3rd World Petrol. Congr.*, 1951, **1**, 220–35. (In French.)—The history of exploration and various research methods relating to the Po Valley are described. The valley forms part of the external fold system of the Apennines, and recent discoveries have proved of much value for other zones in the central and southern part of Italy. Geophysical methods and drilling have shown that many anticlines have a trend parallel to that of the Apennines.

The sediments consist of Oligocene and Miocene sands and shales, which are overlain by practically horizontal Pliocene and Quaternary beds.

The chief reservoirs are in the Upper Miocene, and these produce gas with small amounts of oil; gas is also obtained from Quaternary formations in the eastern part of

the Po Valley. Consideration is given to the possibilities of oil production from structures already located and not yet tested, and also to non-anticlinal reservoirs.
G. S. S.

2832. An accumulation in the faulted blocks of the Oued Beth (French Morocco) basement. La Société Cherifienne des Pétroles. *Proc. 3rd World Petrol. Congr.*, 1951, **1**, 315–328. (In French.)—An unusual form of oil accumulation is found in Morocco in sediments occurring in faulted blocks along the edge of the Palæozoic basement, in the immediate neighbourhood of the outer margin of the Pre-Rif Mesozoic basin.

There are three main producing fields: Baton, Tisserand, and L'Oued Mellah, and production figures and other data concerning them are supplied.

The nature of the reservoir and the method of accumulation place the Oued Beth fields in the same group as certain fields of the "basement complex" of California, particularly so, Edison (Kern County).

Since this paper was written, two new oil pools have been discovered. The field characters confirm the authors' hypothesis on the fundamental relation between the oil accumulations in the fractured rocks of the Palæozoic basement and the contiguous Mesozoic basin.
G. S. S.

2833. The oil possibilities of Turkey with special reference to the Raman field. C. Tasman and N. Egerman. *Proc. 3rd World Petrol. Congr.*, 1951, **1**, 187–98.—Four different areas of Turkey are considered with a view to oil possibilities, viz., Alexandretta Gulf Basin, Northeast Turkey, Thrace in European Turkey, and the southeastern part of the country—Raman. Of these, the only successful field has been Raman, and a separate chapter is devoted to it.

Situated 80 km east of Diyarbakir, the Raman oilfield is a simple elongated asymmetrical anticline, 50 km long and 10 km wide. Overlying the basement complex are Devonian sands and shales, the sands being very bituminous. Permo-Carboniferous rocks follow in the easternmost part of the structure, and these are succeeded by an almost normal succession up to the Cretaceous. From this system (the *Turonian* division) oil is found at Raman in dolomitic limestones, locally known as "massive" limestone. Production comes from the top of the Turonian, and continues to a depth of approx 100 m, and is followed (after a barren zone of 80 m) by another oil-bearing zone of 12 m. Below this there are about 700 m of varied limestones, all showing evidences of asphalt, bitumen, and light-coloured oil. This condition is believed to support the idea of upward migration of oil in the producing Turonian section.
G. S. S.

2834. Observations on the geology and petroleum occurrences of the Middle East. F. R. S. Henson. *Proc. 3rd World Petrol. Congr.*, 1951, **1**, 118–40.—Some factors are outlined which may have affected the pre-Neogene history of oil formation, migration, and accumulation in the Middle East. Incidental references are also made to the geology of surrounding areas. Post-Caledonian history only is considered because marine older Palæozoics were peneplained after a Caledonian orogeny in the northwest; they are here treated as part of the basement in that sector.

The whole of the known and prospective oil-bearing territory of the region lies within the Unstable Shelf (Zone D), which overlaps the earlier assumed boundary between geosyncline and foreland. The marine sediments of this belt are predominantly calcareous, and of chemical or organic origin, with evaporites.

The subdivision of the Middle East into stratigraphic–tectonic zones is reviewed, and previous classifications are compared in a series of tables, together with a map showing the author's own interpretation of zones. He concludes that the formation, primary migration, and accumulation of oil in the Middle East were conditioned by the preorogenetic history of the Unstable Shelf, and that oil in anticlines of Neogene origin must have been secondary and mainly confined to areas of earlier primary accumulation. Thus, in this region, a study of pre-Neogene conditions is fundamental in the search for oil.
G. S. S.

2835. Stratigraphical exploration surveys in south-west Persia. P. E. Kent, F. C. Slinger, and A. N. Thomas. *Proc. 3rd World Petrol. Congr.*, 1951, **1**, 141–61.—The nature of the stratigraphy of Southwest Persia makes the use of palæontology and

micro-palæontology of much importance in oil-exploration work. During field-work several stratigraphical markers were found and traced over great lengths of country, but for detailed subdivision and correlation purposes recourse had to be made to palæontology. Results of this co-operative work are described.

A table is supplied showing the general succession of pre-Fars rocks in the part of the Zagros Ranges adjacent to the oilfield. The oldest rocks are Triassic in age, and these pass upwards to the Lower Miocene; the stratigraphy and palæontology of these deposits are given.

Though there are numerous possible source rocks in Persia, it is still uncertain which of them provided the main source of present-day oil accumulations. There are likewise equally numerous suitable reservoir rocks; included in the more important of these are the Asmari limestone, Middle Cretaceous limestone, and, under suitable conditions, Triassic and Permo-Carboniferous limestones. Isopachyte maps of the various formations have been prepared and accompany the paper. G. S. S.

2836. The Agha Jari oilfield, south-west Persia. D. C. Ion, S. Elder, and A. E. Pedder. *Proc. 3rd World Petrol. Congr.*, 1951, **1**, 162–86.—Agha Jari oilfield, one of the world's largest producing fields, is about 80 miles east of Abadan Island and 40 miles from the shipping terminal at Bandar Mashur; a description is given of its exploration and development.

In almost all proved Southwest Iranian oilfields, a slow upward escape of oil and gas issues from the Asmari reservoir to the surface; this, despite a great thickness of Fars cover rocks. In certain fields such escapes form spectacular oil and gas seepages. The gas gives rise to the phenomenon called Gach-i-Turush (Persian, " sour gypsum "); it is a product of the reaction between the hydrocarbon gases and gypsum, marl, or limestone.

An average Agha Jari well penetrates sediments ranging from Pliocene to Lower Miocene; a succession of these sediments is given. Overlying the main reservoir, condensate oil and high pressure water-shows occur; annual gross production figures are tabulated. G. S. S.

2837. The tectonic framework of the Far East and its influence on the origin and accumulation of petroleum. G. F. Kaufmann. *Proc. 3rd World Petrol. Congr.*, 1951, **1**, 86–117.—From the structural framework of the Far East, certain direct and indirect conclusions are drawn concerning the diastrophic movements within the earth's crust. Three major tectonic classes are recognized: (i) downward rupture (tectogenes), (ii) downwarping of the continental mass of sea floor (idiogeosynclines), and (iii) interior basins or continental depressions formed by: (*a*) crustal downwarp similar to an idiogeosyncline, or (*b*) overthrust of one large continental crustal segment upon another.

Non-marine sediments, which usually occur in tectogenes and interior basins, are the least likely to give rise to oil accumulation. On the other hand, idiogeosynclines, filled with marine sediments, are much more favourable for the origin and accumulation of petroleum.

It is considered that, where exploration data are sparse, oil prospecting areas can be much more satisfactorily rated from an overall tectonic approach than by much data of a purely stratigraphic nature. G. S. S.

Geophysics and Geochemical Prospecting

2838. Prospecting by geophysical methods. D. T. Germain-Jones. *Nature*, 1952, **170**, 230.—Report of a meeting of the European Association of Exploration Geophysicists held in London, May 1952. Summaries and discussions are given of four papers on seismic prospecting, three papers on the gravity method, and two on the telluric current method. H. C. E.

2839. Principal characteristics and results of the gravimetric surveys made in Italy for oil and gas exploration. L. Solaini. *Proc. 3rd World Petrol. Congr.*, 1951, **1**, 240–55.—This report deals with gravimetric surveys made by various societies and institutions, in particular by the "Istituto di Geofisica Applicata" of the Engineering College of Milan. Most of its surveys have been made in the Po plain, and ten different areas covering 7000 sq. km. were surveyed from over 3500 stations.

The known productive structures of the Po plain are situated at depths varying from 1500 to 2000 m, though seismic reflection has revealed folds at depths of over 3000 m. Owing to regional anomalies, special care was needed in detailed surveys in order that local anomalies (which are very weak) should be made clear.

Research on organization and execution, and the methods of obtaining local anomalies are described and illustrated. Observations are also made, founded on experience, on the application of gravimetric methods. G. S. S.

2840. Patents. U.S.P. 2,589,219 (24.4.47; 18.3.52). D. C. Bond and M. Savoy, assrs to The Pure Oil Co. Method of studying oil producing earth formations by injecting a fluid containing acetylene, withdrawing the fluid and testing it for the presence of acetylene.

U.S.P. 2,590,113 (12.3.47; 25.3.52). E. McDermott. Method of geochemical prospecting in which soils samples are burnt at 500° C and then heated in an inert atmosphere at 600° C and the additional CO_2 produced during this heating is measured.

U.S.P. 2,590,530 (10.3.48; 25.3.52). G. M. Groenendyke, assr to Socony-Vacuum Oil Co. Inc. Seismic prospecting system.

U.S.P. 2,590,531 (10.3.48; 25.3.52). K. W. McLoad, assr to Socony-Vacuum Oil Co. Inc. Selector arrangement for seismic prospecting system. J. M. S.

Drilling

2841. Electrical logging in limestone fields. H. G. Doll and M. Martin. *Proc. 3rd World Petrol. Congr.*, 1951, **2**, 394–417.—The conditions prevalent in limestone fields in so far as they affect electrical logging are outlined, and the improvements introduced into the interpretation of conventional logs during the last few years are briefly described. The principles underlying the new methods of logging—selective SP logging, micrologging, induction logging, and Laterolog are indicated and their applications discussed.

Field examples are included. C. A. F.

2842. Theoretical considerations involved in the determination of petroleum reservoir parameters from electric log data. M. R. J. Wyllie. *Proc. World 3rd Petrol. Congr.*, 1951, **2**, 378–92.—Methods of determining interstitial water saturation, salinity, porosity, and permeability from electric logs are reviewed, and it is shown that the calc of interstitial water salinity from the electrochemical component of the SP curve is theoretically justified, particularly when logs show a consistent shale base line.

The calc of accurate formation factors from electric logs is theoretically impossible, since sands never become completely flushed by mud filtrate, but it should be possible to correct the apparent formation factors to enable the average connate water saturation obtained from log data to agree closely with results obtained by core analysis.

A tentative relationship between permeability, formation factor, and connate water saturation is given. C. A. F.

2843. Oil base drilling fluids. G. Miller. *Proc. 3rd World Petrol. Congr.*, 1951, **2**, 321–50.—The use of oil base drilling muds over the last ten years has shown that this type of mud has many advantages over conventional muds; in many cases the use of this mud in the pay zone has resulted in higher initial and cumulative production. Oil base mud also enables more accurate determinations of core analysis data and reservoir conditions to be made.

In general, oil base mud has most of the desirable properties of water base mud and in addition prevents the water blocking or mudding off of pay zones.

The properties and functions of these muds are described and eighteen references given. C. A. F.

2844. Emulsion drilling fluids. D. L. Wilson. *Proc. 3rd World Petrol. Congr.*, 1951, **2**, 360–77.—Emulsion drilling muds have a wide range of properties, performance, and maintenance. They have six main advantages over conventional muds, and these are: lower fluid losses, holes are closer to gauge, greater drilling speed, lower drill pipe

torque, better lubrication, and easier control. The use of a lime base mud provides resistance against contamination by cement, salt, and anhydrite.

Three references. C. A. F.

2845. Drilling emulsion. R. A. Henkes. *Proc. 3rd World Petrol. Congr.*, 1951, **2**, 351–7.—Emulsion muds were introduced in 1943, and they now have important applications in well drilling. The history, preparation, principal properties, and applications of these muds are reviewed and suggestions given for further research.

Emulsion muds were first prepared by emulsifying asphaltic crude into clay mud, which was treated with alkali and tannate. By using suitable emulsions, diesel fuel and paraffinic crude can now be emulsified, but these tend to give greater fluid loss and require the addition of plastering agents such as bentonite and starch.

Emulsion muds generally have a lower filter loss than conventional muds, the gel and visc rising with higher oil concentration, depending on the types of oil used. They have a superior lubricating property, but become easily air-cut; this, however, can be overcome by adapting the mud circulating equipment.

They are ideal for deep and difficult drilling operations, and increased drilling speeds can be obtained in soft formations.

They have wide applications in directional drilling, crooked holes, and fishing operations.

Research in mud additives is recommended to improve the performance of drilling bits.

Six references. C. A. F.

2846. Determination of the oil content of oil-in-water emulsion drilling fluids. R. A. Henkes. *Proc. 3rd World Petrol. Congr.*, 1951, **2**, 357–9.—A technique for the determination of the oil content of oil-in-water emulsion drilling fluids is described.

20 to 40 g of the sample is placed in a porous extraction thimble and suspended beneath a reflex condenser which discharges into a 25-cc graduated trap. The sample is extracted with 200 cc of industrial xylene, which is immiscible with water, until the filtrate from the thimble is colourless and the vol of water separated in the trap is constant. The residue in the thimble is then dried and the weight of oil calc. The method is an adaptation of that described in *U.S. Bur. Min. Rep. Invest.*, 4004, 1946.

C. A. F.

2847. The rheology of drilling mud. R. Métrot. *Proc. 3rd World Petrol. Congr.*, 1951, **2**, 289–303. (In French.)—Various methods have to be used in studying the complex rheological properties of drilling mud.

The Bingham equation, although a valuable working hypothesis, is inadequate to explain all these properties. It is suggested that an equation involving the rigidity modulus and the yield value be used in studying the elastic properties of muds which do not follow Hooke's law, and another equation to define the concept of a dilatant liquid is proposed which avoids the errors introduced by using Navier's law, which does not apply to slow flow.

Exact yield values are difficult to determine due to the necessity of limiting the sample by a wall and the macroscopic heterogeneity of muds.

Eleven references. C. A. F.

2848. The effect of particle size on the physical properties of a Gulf Coast drilling mud. G. H. Fancher and S. C. Oliphant. *Proc. 3rd World Petrol. Congr.*, 1951, **2**, 304–18.—The visc, gel strength, and water loss have been determined for a series of mud systems which have been recombined from fractions, having a limited particle size range, separated from a Texas Gulf Coast shale drilling mud.

It was found that the visc and the standard API water loss were exponential functions of the concentration of the solids and that the water loss at constant visc and a definite concentration of total solids can be changed by approx 25% by changing the distribution of particle size within the range of sizes obtaining in the mud. It was also found that the standard 10 min gel strength of the systems increases linearly with an increase in concentration of solids and that the visc of a drilling mud can be predicted with reasonable accuracy if the distribution of particle size and dilution of the mud are known.

Three references. C. A. F.

2849. Patents. U.S.P. 2,587,638 (27.9.45; 4.3.52). J. H. Meier, assr to Bucyrus-Erie Co. Automatic feed for cable tool drill.

U.S.P. 2,588,210 (18.11.49; 4.3.52). O. W. Crisman and A. J. Teplitz, assrs to Gulf Research and Development Co. Method of locating leaks in a well bore by introducing a mixture of a drilling fluid and fragments of a flexible material, insoluble in the fluid and which contain a radioactive material, also insoluble in the fluid, and then locating depth of the radioactive material by surveying the well for radioactivity.

U.S.P. 2,588,311 (28.10.46; 4.3.52). G. P. Wagner, assr to The Engineering Development Co. Inc. Oil well drilling apparatus.

U.S.P. 2,588,408 (8.5.47; 11.3.52). C. M. O'Leary. Mechanism for operating a rotary well drilling machine and automatically controlling the drill bit pressure.

U.S.P. 2,588,717 (25.5.46; 11.3.52). L. O. Goodwin, assr to Stanolind Oil and Gas Co. Well logging apparatus.

U.S.P. 2,588,746 (29.3.47; 11.3.52). B. R. McKinley. Formation tester and pipe perforator.

U.S.P. 2,588,748 (22.1.47; 11.3.52). J. A. Niles, N. B. Simpson, H. F. Sturgis, R. P. Vincent, and C. W. Ziemer, assrs to Stanolind Oil and Gas Co. Electrical apparatus for measuring well characteristics.

U.S.P. 2,588,808 (14.2.49; 11.3.52). R. D. Dawson, assr to Shell Development Co. Drilling fluid comprising a water-in-oil emulsion, a finely divided solid dispersed therein, and an oil-dispersible polyvalent metal soap of an oxidized resin acid.

U.S.P. 2,589,118 (30.6.45; 11.3.52); U.S.P. 2,589,119 (15.2.46; 11.3.52); U.S.P. 2,589,120 (2.5.46; 11.3.52); U.S.P. 2,589,121 (13.6.46; 11.3.52). C. M. O'Leary. These relate to automatic well-drilling devices and power transmitting apparatus therefor.

U.S.P. 2,589,146 (6.10.49; 11.3.52). C. J. Samuelson. Submersible deep-water drilling apparatus.

U.S.P. 2,589,153 (27.10.47; 11.3.52). A. L. Smith. Submersible barge for drilling sub-aqueous wells.

U.S.P. 2,589,159 (19.2.48; 11.3.52). A. L. Stone, assr to Standard Oil Development Co. Hold-down slip assembly.

U.S.P. 2,589,430 (21.7.50; 18.3.52). W. H. Pletcher. Apparatus for sealing off wells being drilled.

U.S.P. 2,589,483 (6.4.46; 18.3.52). J. E. Eckel and F. Richard, assrs to Oil Center Tool Co. Tubular head for oil wells.

U.S.P. 2,589,506 (15.4.47; 18.3.52). O. L. Morrisett, assr to Halliburton Oil Well Cementing Co. Drillable oil well packer.

U.S.P. 2,589,534 (28.7.47; 18.3.52). R. Q. Buttolph. Well drill guiding assembly.

U.S.P. 2,589,656 (19.6.50; 18.3.52). E. B. Armstrong. Well packer with expandible seals.

U.S.P. 2,589,949 (15.12.49; 18.3.52). V. G. Meadors, assr to Standard Oil Development Co. Drilling fluid comprising an aqueous suspension of clay and *ca* 0·1 to 5% of dioxane or a polyethylene glycol.

U.S.P. 2,590,366 (12.8.46; 25.3.52). W. R. Atwood. Well casing perforating gun.

U.S.P. 2,590,487 (30.11.48; 25.3.52). R. E. Axelstrom. Well rod grab.

U.S.P. 2,590,502 (22.11.48; 25.3.52). C. C. Brown. Slip expander assembly for well tools of the hook-wall type.

U.S.P. 2,590,512 (8.7.46; 25.3.52). R. L. Crain, assr to Gray Tool Co. Oil well swivel. J. M. S.

Production

2850. Directional permeability trends. R. V. Hughes. *Proc. 3rd World Petrol. Congr.*, 1951, **2**, 467–72.—Examination of over 300 cores from the Bradford field, Pennsylvania, has shown that there are directional permeabilities in the planes of bedding showing marked trends at right angles. Min permeabilities, in the direction of the min trends, may be only 60 to 75% of those in the direction of the max trends; the geographical direction of the trends is regular throughout the field. A tentative relationship has been established between these trends and mineral grain orientation for three cores.

The possible significance of directional permeability trends in oil exploration and production is discussed.

Fourteen references. C. A. F.

2851. Some problems of relative permeability measurement. W. Rose. *Proc. 3rd World Petrol Congr.*, 1951, **2**, 446–58.—Factors involved in the planning of laboratory experiments to measure oil recovery are described, and four new techniques are proposed. New gas permeability data are presented.

It is concluded that the Hassler method gives reliable data, but it is advantageous to use the adjustable manometer method, which permits the use of low permeability barrier pads and high displacement factor manometers, which give accurate readings of small pressure gradients.

Fifteen references. C. A. F.

2852. Field processing of oil and gas. K. B. Barnes. *Proc. 3rd World Petrol. Congr.*, 1951, **2**, 278–88.—The broad aspect of field processing operations is described, in their approx sequence as the oil and gas proceeds from the well head.

These processes are: treating and separation, crude oil stabilization, dehydration of gas, desulphurization, special products, cycling, gasoline and LPG, and pressure maintenance. Related processes such as gathering systems, pipeline stations, field laboratories, and research facilities are also discussed.

The purpose of the paper is to present the many important aspects of the work of the petroleum engineer in conducting the most efficient handling of processes in oil and gas fields.

Five photographs of processing plants are included. C. A. F.

2853. Theoretical considerations of multi-phase flow in idealized capillary systems. S. T. Yuster. *Proc. 3rd World Petrol. Congr.*, 1951, **2**, 437–44.—Relative permeability in simple capillary systems has been analysed, and it is indicated that the relative permeability to oil in an idealized capillary system is not a simple function of the saturation, but is dependent on the visc ratio of oil–water. If this ratio is greater than unity, the relative permeability to oil passes through a max as the oil saturation is decreased, giving two saturations at which the relative permeability is the same.

C. A. F.

2854. Pressure build up in wells. D. R. Horner. *Proc. 3rd World Petrol. Congr.*, 1951, **2**, 503–19.—The pressure build-up curve obtained from a closed in well can be analysed by plotting b.h.p. against $\log \frac{t_o + \delta}{\delta}$, where δ is the closed in time and t_o is the past producing life of the well. The permeability of the formation can be determined from the slope of the curve. Methods are also given for extrapolating the recorded pressures to infinite closed in time for: (1) a new well far from any reservoir boundary, (2) a new well close to a fault, but far from any other boundary, and (3) a well in a finite reservoir.

Four references. C. A. F.

2855. The quantitative interpretation of radioactivity logs. R. E. Fearon and E. S. Mardock. *Proc. 3rd World Petrol. Congr.*, 1951, **2**, 418–34.—The application of radioactivity logging to the problem of obtaining quantitative data on porosity is described,

and the application of the Gaussian error theory in the statistical principles underlying the recording of radioactivity measurements is discussed.

The radioactivity logs and porosity data from core analysis are compared for two wells, from the Pegasus field in Texas and the Redwater field in Alberta, and curves showing the relationship of log deflections to neutron derived porosity are given.

Ten references. C. A. F.

2856. The application of surface observations to the study of underground conditions in oil reservoirs. W. J. Baker. *Proc. 3rd World Petrol. Congr.*, 1951, **2**, 474–84.—Methods of calc bottom hole pressures from surface pressures are discussed in detail for closed and flowing oil wells, and the determination of the necessary physical characteristics of the oil is described. The role of special observation wells is emphasized, and the relationship between changes of surface and bottom hole pressures is discussed.

C. A. F.

2857. Recovery of oil in California by secondary methods. Pt 1, San Joaquin Valley oilfields, Pt II, Los Angeles Basin and Coastal oilfields. A. G. Loomis, A. N. Fried, and D. C. Crowell. *U.S. Bur. Mines Rep. Invest.* Nos. 4886, July 1952, and 4887, May 1952.—These reports give descriptions of the various fields and the reservoir and production data, and report the progress made in the gas-injection and water-injection operations in 1950. The characteristics of these Californian reservoirs are compared with those of Eastern and Midcontinent fields in which secondary-recovery methods have been applied. In view of the wide differences in oil and reservoir characteristics, it is inevitable that economic recovery of additional oil in California by secondary-recovery will require considerable modification in the methods generally established in the Appalachian and Midcontinent areas. Some areas of California may require the development of entirely new methods for economic recovery. In particular, differences are encountered in repressuring or water flooding the thick, non-uniform sands, which are faulted and lensed, have extreme variations in permeability, and yield very viscous oils. In some Californian sands the presence of argillaceous material, that swells on contact with water, creates a difficult problem. W. H. C.

2858. Patents. U.S.P. 2,587,879 (4.2.49; 4.3.52). P. H. Nash. Apparatus for liquefying paraffin in wells.

U.S.P. 2,588,296 (15.2.46; 4.3.52). G. F. Russell, assr to Aluminium Co. of America. Method and apparatus for receiving, handling, and treating moisture bearing gaseous hydrocarbon fluid issuing from a well.

U.S.P. 2,588,369 (14.5.47; 11.3.52). C. K. Eilerts, assr to U.S.A. as represented by the Secretary of the Interior. Apparatus for injecting reagent into oil, gas, or gas-condensate wells for dissolving obstructing incrustations.

U.S.P. 2,588,554 (25.10.46; 11.3.52). R. E. Meynig. Apparatus for removing paraffin which has been deposited on the inside of a well tubing.

U.S.P. 2,588,578 (28.6.46; 11.3.52). J. J. Santiago, assr to Grant Oil Tool Co. Well cleaning tool.

U.S.P. 2,589,373 (21.4.47; 18.3.52). W. E. Hammock. Adjustable choke for controlling flow from oil wells.

U.S.P. 2,589,420 (5.5.47; 18.3.52). E. W. Mong and W. O. Anderson. Actuator for reciprocating well pumps.

U.S.P. 2,589,606 (4.3.49; 18.3.52). T. B. Dunn. Formation and casing tester.

U.S.P. 2,589,668–72 (16.5.49; 18.3.52). C. J. Coberly, assr to Dresser Equipment Co. Fluid operated pumps and pump systems for wells.

U.S.P. 2,590,688 (14.11.46; 25.3.52). R. L. Crain, assr to Gray Tool Co. Manifold for use in flowing wells. J. M. S.

Oilfield Development

2859. Oil—the task ahead. H. S. Gibson. *I.P. Review*, 1952, **6**, 294.—Lees and Ion have previously estimated the reserves of oil likely to be proved in 1972, and the rate of consumption at that time, to be 41,000 million tons and 2600 million tons p.a. respectively. The present author points out that this latter figure may be too low, but is not unduly worried, since history indicates that discoveries of oil generally are in excess of the estimate. The distribution of production in 1951 is analysed, it being emphasized that the Middle East is likely to become the main producing area of the world. The technical aspects relating to increased production in the Middle East are then discussed and the economic implications mentioned. It is pointed out that while the former can be predicted and controlled, the latter will necessitate very careful handling. R. H.

2860. The oil industry looks ahead. V. Smith. *I.P. Review*, 1952, **6**, 287.—If oil consumption continues to increase at its present rate, 1967 will necessitate a production at a level equal to twice that of the present time. Greater use of oil products is being made in many directions, and a rapidly increasing fraction of the world's energy requirements is being supplied from petroleum sources. Also the pattern of the oil industry is changing considerably in the following ways: the U.S.A. has now become a net oil importer; Europe imports an ever increasing proportion of its requirements from the Middle East; the importance of gas/diesel and fuel oils has increased considerably since 1938. Thinking of the future, the author points out that demand is likely to increase still further, particularly as economic development of certain parts of the world proceeds. The expected progress in individual products is indicated, the importance of chemicals from petroleum being stressed. R. H.

2861. Three gas-bearing fields in the Po Valley (North Italy). G. Facca. *Proc. 3rd World Petrol. Congr.*, 1951, **1**, 256–65.—In the central sector of the Po Valley lie the gas fields of Caviaga, Ripalta, and Cortemaggiore. The first two are producing, but Cortemaggiore awaits the completion of a pipeline and the gasoline plant.

Caviaga is 26 miles southwest of Milan and, like the other fields, lies on a Miocene anticline covered by gently folded Pliocene deposits. The gas, formed in the Upper Miocene, contains 95·85% methane, and the best wells produce 250,000 cu. m/day. The total production of the field (up to Nov. 1950) was 283 million cu. m.

The *Ripalta Field* is near Crema, a little north of Caviaga. The first well was completed in 1949, and six other wells have since been sunk; all have yielded a large output of methane. Each produces up to 300,000 cu. m/day, and the total production up to Nov. 1950 was 54 million cu. m.

Cortemaggiore lies about 51 miles from Milan. All wells so far drilled have encountered gas-bearing sands in passing from the Pliocene to the Upper Miocene. In addition, three wells have passed through oil-bearing sands, 6 to 8 m thick. Though not in regular production, the field has yielded about 32 million cu. m. of gas, and about 3000 tons of natural gasoline and oil have been recovered. G. S. S.

Transport and Storage

2862. Analysis and design of pipeline spans. P. E. Reynolds. *Oil Gas J.*, 18.8.52, **51** (15), 106.—The application of stress analyses, based on the standard pressure piping code is shown in Pacific Gas and Electric Co. to ensure safe economical design of spans across gullies and canyons. Stress dealt with include transverse tensile, longitudinal tensile, temp, beam, and offsetting types. G. A. C.

2863. Interrelation between (1) terminal design, (2) operation, and (3) deliveries. R. B. Rodgers and S. A. Hallberg. *Oil Gas J.*, 8.9.52, **51** (18), 108.—A review of the Standard Oil Company (Indiana) method of operation of its product pipelines is given. Accurate metering is a fundamental. Pipeline and terminal prover tanks and terminal shipping facilities are dealt with. A graph for determination of tank size is given. G. A. C.

2864. Patents. U.S.P. 2,588,672 (27.4.46; 11.3.52). W. E. Turvey, assr to Universal Oil Products Co. Liquid level control device.

U.S.P. 2,588,875 (16.11.46; 11.3.52). H. A. Quist, assr to Sun Oil Co. Calibrated liquid level gauge for sealed pressure vessels for storage of volatile liquids.

U.S.P. 2,588,876 (18.12.48; 11.3.52). H. A. Quist, assr to Sun Oil Co. Safety hatch for openings in storage tanks containing volatile liquids.

U.S.P. 2,589,095 (20.10.49; 11.3.52). C. D. Laidley. Vapour control system for oil storage tanks.

U.S.P. 2,589,170 (2.12.48; 11.3.52). B. V. Nooy, assr to Standard Oil Development Co. Pipeline scraper trap assembly.

U.S.P. 2,590,066 (Canada 30.6.44; 18.3.52). R. L. Pattinson. Storing fluids in a preformed impervious cavity in a natural rock salt bed beneath the surface of the earth.

U.S.P. 2,590,205 (4.11.47; 25.3.52). F. E. Pierce. Method of preparing a waterproof covering, for example, over stored peat, by forming a covering of comminuted peat and intermittently sprinkling the covering with water containing 1 to 2% of a water-miscible oil, allowing the covering to dry between each sprinkling. J. M. S.

Refinery Operations

Refineries and Auxiliary Refinery Plant

2865. Refiner's notebook. C. A. Dally. *Oil Gas J.*, 11.8.52, **51** (14), 145; 18.8.52, **51** (15), 163; 25.8.52, **51** (16), 161; 1.9.52, **51** (17), 113.—No. 133 deals with butterfly valves, considering design and operating factors, pressure drop characteristics and operating torques. A graph for torques on a 24-inch valve is given.

No. 134 continues on butterfly valves, dealing with sizing and methods of operation. A chart shows operating torque ratio, 14-inch versus 10-inch butterfly valves (equal capacities).

No. 135 in the series is also concerned with butterfly valves, and deals with valve positioners, spring-type diaphragm motors, and flow characteristics.

No. 136, on butterfly valves, deals with capacities at 60° and 70° openings. Figures show variable v dead area with 15% and 40% restriction. G. A. C.

2866. Prevention of mist formation on vapour condensation from gas streams. H. Theile. *Erdöl u. Kohle*, 1952, **5**, 407–12.—Conditions leading to mist formation are considered. Laboratory tests were made (apparatus described and illustrated) with n-hexane and furfural, using O_2-free N_2 as carrier gas. Presence of foreign nuclei is necessary for mist formation, such nuclei can be formed by chemical action, as shown by addition of O_2 to the N_2, use of crude furfural instead of refined or heating of furfural to 300° C to cause decomp; nuclei are probably minute drops of high-boiling material. Mist formation can be reduced by elimination of nuclei by filters, although resultant pressure drop could prove an obstacle in practice. For laboratory application a spinning-band column can considerably reduce or eliminate mist formation. Modification of temp gradient in the condenser can effect mist reduction, and design for a condenser is shown in which suitable heat flow can be created by excess temp of gas/vapour mixture. V. B.

2867. Engineering reference section. L. B. Woolfenden and R. C. Thiele. *Oil Gas J.*, 11.8.52, **51** (14), 143.—Pt 17 on pumps continues with designing for maintenance, and considers dismantling problems, special units, construction materials, and equipment records. G. A. C.

2868. Heat transfer by direct contact between liquid and vapour. R. J. O'Donnell, R. R. Bowles, and E. E. Gullekson. *Chem. Engng Prog.*, June 1951, **47** (6), 309–14.—Performance data of equipment cooling hot C_4 gases by direct contact with a distillate oil have been correlated and the results used to provide a comparison of the relative efficiency of three types of contacting equipment: a conflow downward empty spray

tower, and a counterflow tower with disk and doughnut baffles in one section and perforated side-to-side baffles in another. Results show that the spray tower is more effective than the disk and doughnut section over the entire range studied, and that the side-to-side baffles are more effective than either of the other sections at high vapour and low liquid rates, but are about equal to disk and doughnut baffles at low vapour and high liquid rates. It is concluded that the particular arrangement studied is of advantage where the rapid cooling of a vapour under low pressure is of prime importance. J. G. H.

2869. Heat transfer. B. E. Lauer. *Oil Gas J.*, 18.8.52, **51** (15), 159; 25.8.52, **51** (16), 155; 1.9.52, **51** (17), 119; 8.9.52, **51** (18), 131.—This is Pt 1 of a new series, and gives coeff of heat transfers through film between surface of cool vertical wall and warm gas and warm liquid. Equations, terminology, limitations, and sources of data are given.

Pt 2 continues with coeff of heat transfer through film between surface of cool vertical wall and warm liquid, condensing vapour, and cool gas. Equations, terminology, and references are provided.

Pt 3 deals with coeff of heat transfer through film between surface of warm vertical wall and cool gas, where the gas movement is natural convection, streamline viscous or turbulent flow. Equations, terminology, and references are given.

Pt 4 is on coeff of heat transfer through film between surface of warm vertical wall and cool liquid, where liquid movement is natural convection and streamline (laminar) flow. G. A. C.

2870. Engineering reference section. M. Van Winkle. *Oil Gas J.*, 1.9.52, **51** (17), 109; 8.9.52, **51** (18), 127.—Pt 20 of the engineering reference section gives the first part of a series on fans and blowers, and deals with definitions and applications. A table gives applications, and a figure shows fan static pressure.

Pt 21 continues on fans and blowers, dealing with types and comparisons (radial, propeller, tube axial, and vane axial). G. A. C.

2871. Engineering reference section. E. C. Condict. *Oil Gas J.*, 18.8.52, **51** (15), 155; 25.8.52, **51** (16), 153.—Pt 18 deals with min continuous safe flow of centrifugal pumps. Pump efficiency formulæ are given, taking into account total dynamic head in feet and shut-off pressure.

Pt 19 continues with the min continuous safe flow of centrifugal pumps. Prevention of flashing is discussed, and a figure shows centrifugal pump characteristics. G. A. C.

2872. Patents. U.S.P. 2,589,262 (12.6.46; 18.3.52). P. C. Keith, assr to Hydrocarbon Research Inc. Heat exchanges.

U.S.P. 2,589,350 (8.9.49; 18.3.52). R. S. Edmunds. Rotary cylinder heat exchanger with scraper.

U.S.P. 2,590,145 (13.4.50; 25.3.52). D. Aronson, assr to Elliott Co. Apparatus for continuously purifying a gaseous mixture by heat exchange with a cold liquefied gas.

U.S.P. 2,590,436 (21.6.48; 25.3.52). D. B. Luten, assr to Shell Development Co. Method of controlling the temp of a positioned portion of a reaction mixture undergoing a reversible exothermic chemical reaction.

U.S.P. 2,590,465 (14.11.44; 25.3.52). K. B. Ris, assr to The Griscom Russell Co. Heat exchanger for transferring heat between a fluid and a mixture of gaseous and finely divided solid materials.

U.S.P. 2,590,480 (Netherlands 16.3.48; 25.3.52). H. van der Kolk, assr to Bureau van Tongeren N.V. Cyclone separator for removing dust from gases. J. M. S.

Distillation

2873. Limiting flows in packed extraction columns; correlation for large packings. J. W. Crawford and C. R. Wilke. *Chem. Engng Prog.*, Aug. 1951, **47** (8), 422–31.—Data are reported for limiting flows of various liquids in a 12-inch dia tower packed with

½-, 1- and 1½-inch carbon Raschig rings, and a new correlation is presented which fits available data for columns packed with rings of ¼ to 1½ inch nominal dia and ½-inch Berl saddles and clay spheres. J. G. H.

2874. Distillation in 2-, 4-, and 5·75-inch diameter packed columns. A. C. Heinlen, R. E. Manning, and M. R. Cannon. *Chem. Engng Prog.*, July 1951, **47** (7), 344–6.—The efficiencies of two types of protruded metal packings and 100 mesh ½-inch McMahon packing were determined in 2-, 4-, and 5·75-inch dia columns. Extensive data on efficiency, hold-up, and pressure drop over the complete operating range were obtained. Protruded metal packing (hole size B) proved most efficient in all three columns, showing lowest H.E.T.P. and lowest pressure drop per plate, with marked price advantage over McMahon packing. At any given vapour velocity, hold-up was largest for liquid of lowest density used, flooding velocity was longest for the most dense liquid and liquid velocities down through the packing at any given vapour velocity varied with test mixture and packing. J. G. H.

2875. Patents. U.S.P. 2,587,595 (6.12.49; 4.3.52). H. A. Cheney and J. H. Raley, assrs to Shell Development Co. Hydrogen halide and olefinically unsaturated organic components of a liquid mixture are separated by fractionation in presence of hydrogen sulphide or a thiol.

U.S.P. 2,588,056 (30.9.47; 4.3.52). J. W. Teter and E. W. Shand, assrs to Sinclair Refining Co. Propene and propane are separated by extractive distillation with a solvent comprising acetonitrile and acrylonitrile or monochloroacetonitrile.

U.S.P. 2,588,063 (30.9.47; 4.3.52). S. J. Ways, J. W. Teter, and E. W. Shand, assrs to Sinclair Refining Co. Propene and propane are separated by extractive distillation with a solvent comprising acetamide or propionamide and acetonitrile or propionitrile.

U.S.P. 2,588,272 (30.12.47; 4.3.52). C. E. Morrell, C. S. Carlson, and P. V. Smith, assrs to Standard Oil Development Co. Separating by distillation aqueous mixtures containing at least two normal primary alcohols, branched alcohols, and neutral non-alcoholic oxygenated organic compounds in the C1 to C5 range.

U.S.P. 2,588,305 (7.5.48; 4.3.52). H. E. Sullenger, assr to Phillips Petroleum Co. Process for distilling hydrocarbon mixtures.

U.S.P. 2,589,018 (31.12.48; 11.3.52). C. E. Morrell, F. A. Biribauer, and C. S. Carlson, assrs to Standard Oil Development Co. Continuous distillation process for purification of crude Oxo alcohols.

U.S.P. 2,589,406 (12.4.46; 18.3.52). A. Latham, assr to Arthur D. Little Inc. Distillation apparatus and method. J. M. S.

Absorption and Adsorption

2876. Hypersorption design; modern advancements. C. Berg. *Chem. Engng Prog.*, Nov. 1951, **47** (11), 585–91.—The basic operation of the Hypersorption process which employs a moving bed of activated carbon to adsorb and fractionate components of a gas stream is briefly described, and the design of standard units, together with specific designs and variations in design for special processing operations are outlined. Applications of the process in a variety of operations are indicated with operation sequences. J. G. H.

2877. Lion Oil operates 50,000 M.c.f. gasoline plant in West Texas Canyon Reef area. W. M. Wilson. *Oil Gas J.*, 11.8.52, **51** (14), 94.—The Diamond "M" Sharon Ridge plant processing gas from 560 oil wells is described.

Plant could process 77,000 M.c.f/day with reduced propane recovery; present extraction efficiency is 75%, 98%, and 99% for propane, butanes, and pentanes and heavier, respectively. G. A. C.

2878. Patents. U.S.P. 2,590,148 (22.9.47; 25.3.52). C. H. O. Berg, assr to Union Oil Co. of California. Apparatus for separation of a gaseous mixture by continuous

selective adsorption on a solid granular adsorbent, including means for maintaining the column of flowing granular solids at a constant height.

U.S.P. 2,590,322 (13.12.47; 25.3.52). D. H. Imhoff and C. H. O. Berg, assrs to Union Oil Co. of California. Apparatus for separation of gaseous mixtures by selective adsorption. J. M. S.

Solvent Extraction and Dewaxing

2879. Patents. U.S.P. 2,587,689 (31.3.47; 4.3.52). E. O. Box, assr to Phillips Petroleum Co. Acetylene is separated from gaseous hydrocarbon mixtures by counter-currently contacting the mixture with liquid acetic anhydride, which preferentially dissolves the acetylene.

U.S.P. 2,588,506 (15.4.47; 11.3.52). L. C. Fetterly, assr to Shell Development Co. In the extractive fractionation of organic compounds by means of complex formation with urea or thiourea, a portion of the raffinate is recycled to a point prior to the separation of the complexes.

U.S.P. 2,588,602 (27.12.47; 11.3.52). C. E. Adams and R. A. Dinerstein, assrs to Standard Oil Co. Fractionating a mixture of straight chain organic compounds by contacting with a solution of urea sufficient to form a urea-adduct with all of the highest mol. wt. compound but insufficient to react with all of the compounds and separating the adduct from the mixture.

U.S.P. 2,589,960 (7.11.47; 18.3.52). G. C. Ray, assr to Phillips Petroleum Co. Olefins are separated from saturated hydrocarbons by contacting the mixture with a cuprous salt in *o*-phenetidine.

U.S.P. 2,590,490 (24.5.48; 25.3.52). B. C. Benedict, assr to Phillips Petroleum Co. Process for refining lubricating oil which comprises introducing the lubricating oil stock, a normal paraffin hydrocarbon solvent of ≥ 4 carbon atoms (I) and a hydrogen fluoride-rich phase from a reaction zone (II) into an extraction zone, removing (II) from the extraction zone, removing an oil–(I) phase from the extraction zone to a reaction zone where it is reacted with hydrogen fluoride, separating the effluent from the reaction zone into an oil–(I) phase and (II), cycling (II) to the extraction zone, and separating the oil–(I) phase into (I), which is cycled to the extraction zone, and the treated oil. J. M. S.

Cracking

2880. Fluid catalyst-gas mixing in commercial equipment. J. W. Askins, G. P. Hinds, and F. Kunreuther. *Chem. Engng Prog.*, Aug. 1951, **47** (8), 401–4.—Gas samples withdrawn from various points in the fluid catalyst bed of a 40-ft dia commercial cat cracking regenerator indicate that a high degree of gas down-mixing exists. It appears that most of the gas introduced passes through the bed in the form of bubbles, rather than flowing around and fluidizing the catalyst particles. Thus a fluid bed with a small length to dia ratio may be an inefficient reactor so far as vapour–solid contacting is concerned. The degree of gas down-mixing which exists may make such a system insufficient for carrying out reactions where a high conversion is desired, or where the products formed inhibit the reactions. J. G. H.

2881. Kinetics of regeneration of alumino-silicate catalysts. Oxidation of coke on catalyst in tubes at a varying concentration of oxygen along the catalyst layer. G. M. Panchenkov and N. V. Golovanov. *Izvest. Akad. Nauk S.S.S.R., Otdel. Tekh. Nauk*, 1952, 1031–6.—(Cf. Abs. 2330.) In the fixed-bed process cat regeneration occurs in the reactor tubes. Case is considered when max O_2 concn $\geq 30\%$ and hence oxidn reaction is of the first order. Reaction kinetics are treated mathematically and methods derived for calculating the following: time at which, in a given section of the reactor, at a known distance from the commencement of the reaction zone, a given concn of O_2 will be attained in the regeneration gas; O_2 concn in the regeneration gas a given time after commencement of the reaction, for the case of a fixed cat under isothermal conditions; O_2 distribution along the reaction zone for the case of counter-current flow of the regeneration gas and the cat, in isothermal conditions. V. B.

2882. Patents. U.S.P. 2,587,669 (3.1.50; 4.3.52). W. W. Weinrich, assr to Houdry Process Corpn. Cracking liquid hydrocarbons by means of a hot granular contact mass impelled by a vapour stream up an elongated vertical channel.

U.S.P. 2,587,670 (1.1.50; 4.3.52). W. W. Weinrich, assr to Houdry Process Corpn. Liquid hydrocarbons are processed by contact with hot granular adsorptive contact material impelled upwards by a gas, the hydrocarbons which are not vaporized being adsorbed in the granular material and the granular material thereafter being allowed to form a compact gravitating bed which is used for contacting hydrocarbon vapours, including those formed by the original contact.

U.S.P. 2,587,703 (18.2.48; 4.3.52). R. M. Deanesly, assr to Universal Oil Products Co. Autothermic cracking of heavy oils by preheating a heavy oil stream, dispersing it mixed with oxygen into a small reaction zone at 1200° to 1700° F and at a super-atmospheric pressure <3 atm, and passing the products through a fluidized bed of coke particles which traps tar fog.

U.S.P. 2,587,729 (31.5.46; 4.3.52). L. C. Huff, assr to Universal Oil Products Co. Process for conversion of a mixture of solid and liquid hydrocarbons comprising pre-heating, flashing off and fractionating light components, passing a heated vapour stream through the heavy residue to effect coking and distillation, fractionating these distillation products, recycling the intermediate fraction as the heated vapour stream for the coking operation, subjecting heavy fractions from both fractionations to a separate coking, and passing the products thereof to the second fractionation.

U.S.P. 2,589,124 (1.5.50; 11.3.52). J. W. Packie, assr to Standard Oil Development Co. Method of controlling rate of flow of fluidized solids between two contacting vessels.

U.S.P. 2,589,189 (17.8.49; 11.3.52). F. G. Ciapetta and W. H. Buck, assrs to The Atlantic Refining Co. Catalyst comprising 80 to 95% silica gel and 5 to 20% alumina, impregnated with 0·1 to 10% of a metal of Group VIII of the periodic system.

U.S.P. 2,589,984 (1.7.47; 18.3.52). W. H. Borcherding, assr to The M.W. Kellogg Co. In a fluidized catalytic cracking process one stream of hot regenerated catalyst passes from the regeneration zone to the conversion zone and another to the stripping zone and catalyst from the latter stream mixes with catalyst from the conversion zone in the upper part of the stripping zone, where it is stripped and passed on to the regeneration zone.

U.S.P. 2,590,539 (14.10.47; 25.3.52). T. B. Hudson, assr to Phillips Petroleum Co. Catalysed exothermic reactions are carried out by causing the fluid reaction mixture to flow through the reaction zone with the temp increasing in the direction of flow, introducing solid mobile catalyst at a number of points in the reaction zone, causing the catalyst to flow counter-currently to the reaction mixture, and controlling the quantity and activity of catalyst introduced at each point to provide a decreasing amount of catalyst activity in the direction of flow of reactants as an inverse function of the temp.

J. M. S.

Hydrogenation

2883. Patent. U.S.P. 2,588,359 (16.2.49; 11.3.52). H. C. Chitwood, J. T. Fitzpatrick, G. W. Fowler, and B. T. Freure, assrs to Union Carbide and Carbon Corpn. Hydrogenation catalyst stabilized for operation as a dehydrogenation catalyst consisting of nickel, copper, chromium (mostly in the form of its oxide), and an alkali metal sulphate.

J. M. S.

Polymerization

2884. Patents. U.S.P. 2,588,358 (22.4.48; 11.3.52). C. S. Carlson, R. S. Merrington, and F. A. Biribauer, assrs to Standard Oil Development Co. Selective liquid phase polymerization of propylene to produce C_9 to C_{24} polypropylenes using as catalyst a solution of a BF_3-di-*iso*propyl ether complex in a BF_3-diethyl ether complex and supplying additional BF_3 to the reaction mixture.

U.S.P. 2,588,425 (4.12.47; 11.3.52). D. R. Stevens and R. S. Bowman, assrs to Gulf Research & Development Co. Tetra-*iso*butylene is prepared by contacting di-*iso*butylene with a boron trifluoride-ether complex at 0° to 55° C.

U.S.P. 2,588,426 (4.12.47; 11.3.52). D. R. Stevens and R. S. Bowman, assrs to Gulf Research & Development Co. Tri-*iso*butylene is prepared by introducing *iso*-butylene into an equimolecular boron trifluoride–ether complex at the max absorption rate and at 15° to 70° C, washing the product with aqueous alkali and water, and fractionally distilling the washed product.

U.S.P. 2,588,975 (16.1.50; 11.3.52). C. F. Fryling and A. E. Follett, assrs to Phillips Petroleum Co. Synthetic rubber by copolymerization of 1 : 3-butadiene and styrene in an aqueous medium in presence of di-*iso*propylbenzene hydroperoxide, an alkyl mercaptan, a soap, and iron pyrophosphate.

U.S.P. 2,589,166 (31.12.46; 11.3.52). B. M. Vanderbilt and F. Bascom, assrs to Standard Oil Development Co. Ketone soluble copolymer of methacrylonitrile and a conjugated diolefin prepared from an aqueous emulsion of the monomers in presence of an oxygen yielding copolymerization catalyst and an aliphatic mercaptan.

U.S.P. 2,589,258 (1.2.50; 18.3.52). E. C. Howard, assr to E.I. du Pont de Nemours & Co. Aqueous dispersion polymerization of ethylenically unsaturated compounds in presence of cupric or ferric ions, a peroxide, and a hydrazodisulphonate ion.

U.S.P. 2,589,919 (19.12.47; 18.3.52). E. Arundale and F. Bascom, assrs to Standard Oil Development Co. Latex of high solids content is prepared by the emulsion copolymerization of a conjugated diolefin and acrylonitrile, using a potassium soap of a fatty acid or alkyl sulphate as emulsifier, and in presence of an alkali persulphate, a sodium or ammonium salt of hydrochloric, phosphoric, sulphuric, sulphurous, acetic, or pyrophosphoric acid, and an alkali salt of a formaldehyde–naphthalenesulphonic acid condensation product. J. M. S.

Alkylation

2885. Patents. U.S.P. 2,589,057 (12.8.48; 11.3.52). B. B. Corson and W. M. Kutz, assrs to Koppers Co. Inc. Process for transferring an alkyl group from a polysubstituted aromatic compound to an alkylatable aromatic compound which comprises subjecting a mixture of the compounds, in a mol ratio of 1 : 2·5, to the action of an alkylation–dealkylation catalyst at a pressure of 15 to 60 atm and at a temp below 450° C.

U.S.P. 2,589,253 (30.1.46; 18.3.52). G. L. Hervert and H. S. Bloch, assrs to Universal Oil Products Co. Alkyl benzenes are alkylated by treatment with a normally liquid olefin in a mol ratio of 4 : 1 in presence of a calcined composite of an acid of phosphorus and a siliceous adsorbent at 150° to 375° C and under sufficient pressure to maintain the reactants liquid.

U.S.P. 2,589,523 (21.6.48; 18.3.52). B. B. Woertz, L. M. Henderson, and C. M. Ridgway, assrs to The Pure Oil Co. Alkylated benzene hydrocarbons are made by contacting a mixture of paraffinic and naphthenic hydrocarbons, consisting of two fractions of virgin naphtha boiling in the ranges 190° to 300° F and 400° to 500° F, with a dehydrogenation catalyst in presence of hydrogen at 850° to 1100° F.
J. M. S.

Isomerization

2886. Patent. U.S.P. 2,589,621 (15.12.48; 18.3.52). A. P. Lien and D. H. McCaulay, assrs to Standard Oil Co. Mesitylene is prepared from its trimethylbenzene isomers by isomerization in the liquid phase at 150° to 400° F in presence of $\leq$15 vol-% liquid hydrogen fluoride and $\leq$0·75 mol of boron trifluoride per mol of trimethylbenzene.
J. M. S.

Chemical and Physical Refining

2887. How to rid natural gas of undesirable sulphur compounds. L. Culbertson and J. S. Connors. *Oil Gas J.*, 11.8.52, **51** (14), 114.—Caustic soda, iron oxide, soda ash, two stage phenolate, and phosphate gas treaters to remove hydrogen sulphur and/or carbon dioxide are briefly reviewed. The modern aqueous amine gas treater is discussed in detail, and costs analysed. G. A. C.

2888. Desulphurizing action of Troshkov kaolin. E. A. Timofeeva, N. I. Shuikin, and V. M. Kleimenova. *Izvest. Akad. Nauk S.S.S.R., Otdel. Khim. Nauk*, 1952, 489–94.—Tests were made with non acid-activated clay at 400° C using 64° to 200° C gasoline containing 0·19% S. Reduction of S by up to 90% was achieved after clay had been recovered, thermal regeneration (air at 500° C) having activating effect and increasing clay effectiveness by factor of 3. Trials were also carried out with S-free gasoline containing added S compounds (propyl mercaptan, di-*iso*amyl sulphide, thiophane, thiophene) completeness of S removal being in that order, and varying from 96% (mercaptan S) to 34% (thiophene S). V. B.

2889. Patents. U.S.P. 2,587,640 (12.8.47; 4.3.52). H. Miley, assr to L. Sonneborn Sons, Inc. Sulphuric acid sludge from petroleum refining is treated with superheated steam at above 500° F to coke the hydrocarbon material in the sludge, the gaseous decomposition products being subjected to water condensation, and sulphur dioxide being recovered in a highly pure state.

U.S.P. 2,587,643 (287.8.47; 4.3.52). H. C. Myers, assr to Socony-Vacuum Oil Co. Inc. Petroleum oils are deasphalted by means of a conventional deasphalting solvent mixed with 1 to 20 vol·% of an organic carbonate.

U.S.P. 2,587,987 (10.5.49; 4.3.52). L. V. Franklin, assr to Gulf Oil Corpn. Selective hydrodesulphurization of petroleum hydrocarbons by fractionating charge stock into a number of fractions, contacting a high boiling fraction with a hydrogenation catalyst in presence of hydrogen, adding a lower boiling fraction, heating the mixture, and contacting it with a hydrogenation catalyst.

U.S.P. 2,588,346 (22.10.49; 11.3.52). G. R. Bond, assr to Houdry Process Corpn. Liquid petroleum fractions are refined by treatment with an aqueous solution of antimony trichloride.

U.S.P. 2,589,187 (2.10.47; 11.3.52). E. B. Backensto, assr to Socony-Vacuum Oil Co. Hydrocarbons are desulphurized by treatment with an aqueous alkaline solution containing a water-insoluble fraction of a steam distillate of thiophene tar.

U.S.P. 2,589,450 (22.5.48; 18.3.52). J. P. Stanton, assr to The Pure Oil Co. Sweetening gasoline by contacting with an alkali metal hydroxide solution in presence of free oxygen and a phenolic type oxidation catalyst and removing discoloration from the sweetened product by contacting with an alkanolamine.

U.S.P. 2,589,663 (4.3.44; 18.3.52). D. C. Bond, assr to The Pure Oil Co. Removal of heavy mercaptans from hydrocarbons by aqueous alkali metal hydroxide solutions containing an oxidation promoter and sufficient mercaptides to protect said promoter, adding light mercaptans to the spent solution and regenerating the solution by oxidizing all the heavy mercaptides and a portion of the light mercaptides.

U.S.P. 2,589,981 (16.7.48; 18.3.52). R. L. Weeks, assr to Standard Oil Development Co. Aromatics are removed from gas oils and lubricating oils by treatment with silica gel. The aromatics are removed from the gel by treating it with a liquid paraffin of 4 to 8 carbon atoms, and the gel is then treated with superheated vapours of the same paraffin. J. M. S.

Special Processes

2890. Obtaining of styrene by the contact-catalytic dehydrogenation of the ethylcyclohexane fraction of Maikop gasoline. N. I. Shuikin and I. I. Levitzkii. *Izvest. Akad. Nauk S.S.S.R., Otdel. Khim. Nauk*, 1952, 498–504.—Cat (alumino-vanadium at 547° to 600° C in presence of 5·6 litres CO_2/15 ml liq feed) dehydrogenation of 127° to 134° C

fraction (aromatic content 26%) from Maikop S.R. gasoline, of aromatization product (platinized charcoal at 300° C) thereof, and likewise of ethylbenzene/xylene concentrate obtained from latter by azeotropic dist with MeOH was studied. Results indicate that no appreciable yield improvement is obtained by preliminary aromatization as compared to direct dehydrogenation of the ethyl*cyclo*hexane-containing fraction, which thereby yields approx 11% styrene. V. B.

2891. Patents. U.S.P. 2,587,858 (Netherlands 2.5.47; 4.3.52). A. I. M. Keulemans, assr to Shell Development Co. In the Oxo process using a fixed bed of cobalt catalyst, cobalt is continuously supplied to the reactor in the form of cobalt hydrocarbonyl.

U.S.P. 2,588,260 (12.8.47; 4.3.52). C. S. Lynch and E. S. Corner, assrs to Standard Oil Development Co. An oxygen carrier for the oxidation of hydrocarbons to carbon monoxide and hydrogen consists of iron oxide, manganese oxide, and magnesium or chromium oxide, compounded by coprecipitation of the oxides from mixed aqueous solutions of their salts.

U.S.P. 2,588,323 (3.9.49; 4.3.52). L. Kniel, assr to The Lummus Co. Production of ethylene from gaseous hydrocarbon mixtures.

U.S.P. 2,588,331 (20.3.48; 4.3.52). N. Titlestad, assr to Nicolay Titlestad Corpn. Acid sludges containing sulphuric acid, water, and hydrocarbons, such as are obtained in the alkylation process for producing gasoline, are heated to the b.p. of 98% H_2SO_4 and treated with sufficient SO_3 to react with the hydrocarbons present to form SO_2 and CO_2. The heat of this reaction is used to boil excess water out of the system, and 98% H_2SO_4 is withdrawn from the reactor.

U.S.P. 2,588,452 (10.5.46; 11.3.52). E. T. Layng, assr to Hydrocarbon Research Inc. Liquid hydrocarbons and oxygenated hydrocarbons are made by passing carbon monoxide and hydrogen through a fluidized mass of a spent iron catalyst from ammonia synthesis at 425° to 700° F and under superatmospheric pressure.

U.S.P. 2,588,511 (11.4.49; 11.3.52). A. H. Friedman and J. N. Moran, assrs to Phillips Petroleum Co. Hydrocarbons are synthesized by contacting carbon monoxide and hydrogen at 175° to 325° C with a catalyst consisting of a reduced, ground, fused mixture of iron oxide and a mixed silicate of aluminium and an alkali or alkaline earth metal.

U.S.P. 2,588,639 (4.5.48; 11.3.52). R. J. Lee and P. D. May, assrs to Pan American Refining Corpn. A HF-polyolefinic hydrocarbon complex is contacted with aqueous HF solution first at a temp below 85° F and then at a higher temp below 200° F to hydrolyse the complex.

U.S.P. 2,588,794 (25.7.46; 11.3.52). P. D. Barton, assr to Sun Oil Co. Removing oil from an oil-in-water emulsion by passage through a bed of glass wool to coalesce the oil, allowing the oil to separate and removing from the water.

U.S.P. 2,589,198–201 (12.4.50; 11.3.52). L. T. Monson, assr to Petrolite Corpn Ltd. These all relate to the breaking of oil-in-water emulsions. The compounds used include substituted imidazolines and condensation products of polyhalogenated organic compounds with polymers of tertiary amino ether alcohols.

U.S.P. 2,589,273 (17.9.48; 18.3.52). C. W. Montgomery and W. I. Gilbert, assrs to Gulf Research & Development Co. A synthetic motor fuel containing olefins and oxygenated compounds obtained by the Fischer–Tropsch process is deoxygenated and isomerized by passing it at 300° to 600° C over alumina impregnated with hydrogen chloride.

U.S.P. 2,589,380 (16.11.49; 18.3.52). H. V. Hess, G. B. Arnold, and J. K. Truitt, assrs to The Texas Co. Normal and α-substituted normal aliphatic hydrocarbons are separated from organic mixtures by contacting the mixture with 4 : 4′-dinitrodiphenyl below 160° F to form a solid complex with the said hydrocarbons and separating the complex from the mixture.

U.S.P. 2,589,648 (26.5.50; 18.3.52). F. T. Wadsworth, assr to Pan American Refining Corpn. *cyclo*Alkanes containing 4 to 6 carbon atoms are oxidized to alkane dicarboxylic acids by oxidizing a solution of the *cyclo*alkane in acetone in presence of a polyvalent heavy metal catalyst and *cyclo*hexanone reaction initiator.

U.S.P. 2,589,925 (9.5.47; 18.3.52). V. L. Cain and C. E. Hemminger, assrs to Standard Oil Development Co. Fischer–Tropsch process using as catalyst a fluidized bed of powdered iron which has been pretreated with a CO-rich gas so that it contains 1 to 3·5 wt-% of carbide carbon in the form of Fe_2C.

U.S.P. 2,589,969 (7.1.50; 18.3.52). H. G. Schutze and E. F. Wadley, assrs to Standard Oil Development Co. Fulvene hydrocarbons are produced by contacting a mixture of a hydrocarbon containing 5 to 9 carbon atoms and a methylene group allyl to two double bonds or a polymer thereof and a carbonyl compound having 2 to 5 carbon atoms, in the vapour phase at 400° to 900° F with aluminium, magnesium, or silicon oxide.

U.S.P. 2,590,124 (8.6.46; 25.3.52). W. H. Reeder, assr to Clark Bros Co. Inc. Saturated aliphatic hydrocarbon gases are partially oxidized by mixing with sulphur trioxide and contacting with an adsorptive carbonaceous, silicious, or aluminiferous material at 175° to 450° C.

U.S.P. 2,590,426 (28.5.45; 25.3.52). A. Loverde, assr to U.S.A. as represented by the U.S. Atomic Energy Commission. Photochemical chlorination of heptane by bringing heptane, under actinic light, in contact with chlorine diluted with an inert gas at a temp rising gradually from 25° to 50° C for *ca* 48 hr, then in contact with undiluted chlorine for a further period of *ca* 80 hr at a temp rising gradually to *ca* 150° C.

U.S.P. 2,590,433 (13.5.49; 25.3.52). O. A. Blum, assr to The M.W. Kellogg Co. Polychlorohydrocarbons are de-chlorinated by reaction with a metal at $<75°$ C in the liquid phase and in presence of an acidified solvent containing 0·01 to 5 mol-% of acid.

J. M. S.

Metering and Control

2892. Principles of automatic control. A. Pollard. *Petroleum*, Sept. 1952, **15** (9), 237–9.—The objects of automatic control are discussed, together with the concept of the closed loop and the present status of process analysis, measuring, and controlling instruments. R. E. P.

2893. Recent developments in refinery control. I—Graphic panels at Dunkirk. Anon. *Petroleum*, Sept. 1952, **15** (9), 240–1.—Describes the controls at the Dunkirk refinery owned by the Société Générale des Huiles de Pétrole B.P., which has a designed throughput of 1,400,000 tons a year. This modern integrated refinery is notable for its high throughput and low storage capacities between stages. Measuring and control instruments are therefore required with a very fast response, together with a control panel displaying the variables in as simple and logical a manner as possible. The graphic panels used are in effect flow diagrams of the processes used, and are miniature working replicas of the processes. Any variable is instantly identifiable. R. E. P.

2894. Recent developments in refinery control. 2—Electronic controls at Llandarcy. Anon. *Petroleum*, Sept. 1952, **15** (9), 242.—The new sulphur dioxide extraction plant at Llandarcy, in South Wales, is believed to be the first refinery plant in the world to be completely controlled electronically. This plant is claimed to have marked a considerable technical advance in instrumentation and process control.

The advantage of electronic as opposed to pneumatic operation is stated to lie in the fact that the response is virtually instantaneous, irrespective of the distance between the plant and control room. The plant designed for an output of 330 tons/day, is now operating at 500 tons. R. E. P.

2895. Engineering uses of analogue computing machines. C. B. Crumb. *Mech. Engng*, Aug. 1952, **74** (8), 635.—Various types of analogue computers are described, and the types of problem for which these machines can be used with advantage are listed. Applications include the analysis and design of closed-cycle automatic control systems, temp control systems, and continuous liquid fuel combusion equipment. The procedure for analogue computer operation is set down. Fourteen references.

T. T.

PRODUCTS

Chemistry and Physics

2896. An empirical equation for thermodynamic properties of light hydrocarbons and their mixtures : constants for twelve hydrocarbons. M. Benedict, G. B. Webb, and L. C. Rubin. *Chem. Engng Prog.*, Aug. 1951, **47** (8), 419–22.—An empirical equation is described which represents the following classes of light hydrocarbons and their mixtures in either gaseous or liquid phases : (*a*) pressure–volume–temp–composition data ; (*b*) isothermal change of ethalpy and entropy with pressure ; (*c*) latent heats of vaporization and heats of mixing ; (*d*) fugacities and liquid–vapour equilibria. Numerical data for these constants for methane, ethane, propane, *n*-butane, propylene, *iso*butylene, *iso*pentane, *n*-pentane, *n*-hexane, and *n*-heptane are tabulated. The equation and tabulated values of the constants provide a compact summary of all the thermodynamic properties just listed for any mixture of these hydrocarbons. A comparison is made of the properties observed for these individual hydrocarbons with properties indicated by this equation. J. G. H.

2897. An empirical equation for thermodynamic properties of light hydrocarbons and their mixtures; fugacities and liquid–vapour equilibria. M. Benedict, G. B. Webb, and L. C. Rubin. *Chem. Engng Prog.*, Sept. 1951, **47** (9), 449–54.—Previous papers in this series have described a group of empirical equations for representing certain thermodynamic properties of mixtures of light hydrocarbons in either the gaseous or liquid phase. Present paper compares liquid–vapour equilibria for twelve mixtures of methane, ethylene, propane, *iso*butane, *n*-butane, *n*-pentane, and *n*-heptane evaluated by the equation with equilibria observed experimentally for these mixtures. In all cases good agreement between predicted and observed equilibria has been found ; it is accordingly concluded that the equation may be used with confidence to predict liquid–vapour equilibria in mixtures of all the twelve hydrocarbons used in the series. J. G. H.

2898. An empirical equation for thermodynamic properties of light hydrocarbons and their mixtures; reduction of equation to charts for prediction of liquid–vapour equilibria. M. Benedict, G. B. Webb, L. C. Rubin, and L. Friend. *Chem. Engng Prog.*, Nov. 1951, **47** (11), 571–8 ; Dec. 1951, **47** (12), 609–20.—Equations representing fugacities and liquid–vapour distribution coeff in mixtures of light hydrocarbons developed in previous papers of this series are reduced to chart form to facilitate engineering application. A set of 324 charts has been prepared for the twelve hydrocarbons : methane, ethylene, ethane, propylene, propane, *iso*butane, *iso*butylene, *n*-butane, *iso*pentane, *n*-pentane, *n*-hexane, and *n*-heptane at twenty-six pressures between 14·7 and 3600 lb/sq. in. abs., covering a temp range of −100° to +400° F and a range of molal average boiling points from −225° to +180° F. The charts may be used for the prediction of dew points, bubble points, and equilibrium flash separations with an accuracy sufficient for most engineering purposes. J. G. H.

2899. Oxidation of monoethenoid fatty acids and esters. Union of gaseous oxygen with ethyl, *n*-propyl, and *n*-butyl oleate. A. J. Feuell and J. H. Skellon. *J. Chem. Soc.*, 1952, 59.—The oxidation of ethyl, *n*-propyl, and *n*-butyl oleates at temp up to 120° C, in the presence of uranium oleate catalyst was studied. Peroxide formation with subsequent decomposition at the higher temp was observed. The nature of the terminal alkyl group and the configuration of the mono-ethenoid acid mol influence the course and speed of reaction. J. H. P.

2900. Isomerization of *p*-xylene. G. Baddeley *et al. J. Chem. Soc.*, 1952, 100.—Contrary to previous reports in the literature, it has been demonstrated that the presence of a third component, such as hydrogen halide, is essential for the interaction of an aromatic hydrocarbon and an aluminium halide at room temperature. The rate of isomerization of *p*-xylene was shown to increase with the concentration of hydrogen bromide and the isomerization shown to be not due to demethylation and

subsequent remethylation. Ternary complexes of the type $(ArH)_x(HBr,AlBr_3)_y$ were obtained, and a product believed to be $(m\text{-xylene})_3(HBr,AlBr_3)_2$ was examined. J. H. P.

2901. Determination of vapour pressures of the order of 1 mm of mercury by a modification of Smith and Menzies's method. The vapour pressure of dimethylnitramine. R. S. Bradley *et al. J. Chem. Soc.*, 1952, 740.—A description, with diagram, of apparatus and experimental details of a method for which good reproducibility is claimed. J. H. P.

2902. Adsorption method of measuring surface areas. R. M. Barrer *et al. J. Chem. Soc.*, 1952, 1736.—A discussion of the accuracy of the adsorption method based on consideration of the Brunauer, Emmett, and Teller-type multi-layer isotherms derived from experimental sorption data obtained with montmorillonite and attapulgite. It is suggested that when the isotherms are in good agreement with the experimental data the adsorption method can be a good absolute measure of surface area, but when the isotherm fit is not good, surface areas determined by the adsorption method may not be accurate. J. H. P.

2903. Solutions of metal soaps in organic solvents. Pt III. The aggregation of metal soaps in toluene, *iso*-butyl alcohol, and pyridine. S. M. Nelson and R. C. Pink. *J. Chem. Soc.*, 1952, 1744.—Using an ebullioscopic method, of which full details are given, it was shown that in toluene the degree of aggregation of a number of metal soaps is dependent upon chain length and the polarity of the soap. The more polar soaps are insoluble or form larger micelles. In the polar solvents *iso*butyl alcohol and pyridine the associating effect of the soap dipoles is reduced, and unimolecular solutions are obtained at low concentration. J. H. P.

2904. Densities of some binary liquid mixtures. Pt 1. V. S. Griffiths. *J. Chem. Soc.*, 1952, 1326.—Densities at 25° C of binary mixtures of water with dioxan, acetone, and pyridine, and of mixtures of ethanol and pyridine are reported. J. H. P.

2905. The comparative ease of oxidation of various ethers in the gaseous phase. T. A. Eastwood and C. Hinshelwood. *J. Chem. Soc.*, 1952, 733.—A comparative study is reported of the effect of structure and substitution on the phenomena associated with the oxidation of the homologous series of the ethers. The general kinetic relationships and the role of peroxides in the slow reaction and in the cool flames are considered, and the comparative reactivity of the members of the series was studied. J. H. P.

2906. Measurements of the ultrasonic velocity in some mixtures of liquids. I. Gabrielli and G. Poiani. *Ric. Sci.*, 1952, **22**, 1426–32.—Following foregoing measurements, the curves of the ultrasonic velocity and adiabatic compressibility in some binary mixtures of organic liquid were studied. The method of diffraction fringes of Lucas and Biquard was performed, with ultrasonic frequency of 6·4 Mcycles/sec.

In the mixtures methyl (ethyl) alcohol–ethyl ether the compressibility *v* composition is found to be almost linear, and this is assumed caused by two opposed effects: the breakdown of the associations between alcohol molecules and the interaction between molecules of different kind.

The common characteristic of the systems *cyclo*hexane–acetone and *cyclo*hexane–ethyl alcohol seems to be the removal of the second component molecules one from the others by *cyclo*hexane. This could explain the higher values of the compressibility found for intermediate compositions.

In the mixture aniline–nitrobenzene an almost linear compressibility is found, while the mixture aniline–ethyl alcohol shows the shape of the compressibility curve of the nitrobenzene–ethyl alcohol system. (Author's Summary.)

2907. P.V.T. relations of gases. H. P. Meissner and R. Seferian. *Chem. Engng Prog.*, Nov. 1951, **47** (11), 579–84.—Experimental compressibility factors of gases have been found to deviate from those predicted by standard compressibility charts: the magnitudes of the deviations are shown to correlate with Z_c, the compressibility factor

at the initial point for the gas in question. A graphical analysis of these deviations is presented whereby the compressibility factors read from a standard compressibility chart can be corrected. J. G. H.

Analysis and Testing

2908. Determination of divinylacetylene in synthetic acrylo-nitrile. M. de Maldé, C. Mussa, I. V. Nebbia, and L. Nebbia. *Chim. Anal.*, 1952, **34**, 172–5.—Two methods for detecting traces of divinylacetylene (DVA) are proposed. Nephelometric estimation by complex formed between $HgSO_4$ (in H_2SO_4) and DVA can be used for contents of latter down to order of 0·001%; for lesser quantities (down to about 0·0001%) a U.V. spectrometric procedure is described, samples with DVA content >0·005%, require dilution. Other probable impurities in the acrylo-nitrile do not interfere with these methods. Infra-red spectra are not suitable for DVA contents <0·1%. V. B.

2909. New method for stalagmometric measurement of interfacial tension. A. Philippovich. *Erdöl u. Kohle*, 1952, **5**, 412–17.—Basis of stalagmometric method is discussed and new pattern of capillary described; this has internal dia 2·65 mm, tip dia 0·87 mm, length of graduated section 6 cm, and can function with ¼ ml fluid. Time of outflow (controlled by pinchcock) influences result, and for oils of visc ≯150 cs a figure of ≮150 sec for a 1-cm section of capillary is recommended. Test results are given on nineteen fluids (seventeen hydrocarbons, two alcohols), and are compared with those yielded by du Nouy instrument, the disadvantages of which are discussed. 63% of the results agree within 5% with the du Nouy method; this proportion is considerably increased if a correction factor, depending on the density of the test fluid, is applied. Method is not applicable to liquids containing water-sol components. Rapidity and simplicity of operation, ease of cleaning, and cheapness of the apparatus are claimed as advantages of the new method. V. B.

2910. Application of infra-red spectroscopy to lubrication engineering. G. Rappaport. *Lubr. Engng*, June 1952, **8** (3), 129–34.—The principles of infra-red spectroscopy are briefly summarized and the advantages of infra-red analysis indicated. Equipment used by USAF for this purpose is described together with applications to the identification of additives and to the investigation of fretting corrosion. The possibilities of punched cards for the filing of special data are touched on, and possible new applications enumerated. J. G. H.

2911. Effect of shear temperature on viscosity in rotational viscometer measurement. R. N. Weltmann and P. W. Kuhn. *J. Coll. Sci.*, 1952, **7**, 218–26.—A method is described which permits determination of the approx temp distribution over the cross-sectional area of a Newtonian material which is subjected to shearing forces in a rotational viscometer. By correlating the change of visc to temp increases, and by determining the actual visc value as found in the rotational viscometer, the effect of thixotropy can be studied.

Temp calculations for various operational conditions of a rotational viscometer have been made with regard to a polybutylene oil and a silicone fluid. It appears that where previously the presence of thixotropy was suspected, temperature increases might be responsible for the low viscosity of the polybutylene oil; for the silicone fluid thixotropic behaviour must still be postulated to explain the experimental results. H. C. E.

2912. Band viscometer. H. H. Hull. *J. Coll. Sci.*, 1952, **7**, 316–22.—The construction and operation of a band viscometer are described. The instrument has the following advantages: (1) the sample is subjected to a uniform shearing force throughout the test; (2) the heat energy formed during testing is dissipated efficiently; (3) the instrument operates at rates of shear up to 10,000 sec^{-1}. H. C. E.

2913. Rheology of a lubricating oil at temperatures below the pour point. S. P. Jones and J. K. Tyson. *J. Coll. Sci.*, 1952, **7**, 272–83.—The behaviour of a Pennsylvania neutral oil (pour point −15° C) in a rotational concentric-cyl viscometer has

been examined at −25° and −30° C. It is found that two processes occur simultaneously : (*a*) a degeneration of the rigid structure, predominantly observed at low rates of shear and occurring very rapidly at high rates of shear ; (*b*) a reversible apparent thixotropy occurring predominantly at high rates of shear. It is calculated that temp effects due to frictional heating are sufficient to account for a large part of the reversible thixotropic effect.

The behaviour of the same oil containing *n*-octacosane was studied in a Stormer viscometer at very low rate of shear at 30° C. At this temperature the system was solid. The system exhibits a progressive increase in fluidity as a function of work done in shearing and a transition from plastic to Newtonian flow. It is suggested that the wax crystals existing in the saturated solution have grown together at the points of contact, and that this matrix is mechanically degraded due to shearing. H. C. E.

2914. Sensitive method for the detection of traces of water in oil. J. E. C. Stringer. *Nature*, 1952, **169**, 1109.—A correction to Abs. 1684. The proposed method gives results not in agreement with the commonly accepted values of water content in " bright " oils, and can be used only if emulsions of known water content are available for calibration purposes. H. C. E.

2915. Modern techniques in petroleum testing. X. Mechanical tests for lubricants. H. L. Bingham. *I.P. Review*, 1952, **6**, 207.—Although analytical and physical tests provide essential data for the comparison of lubricants, the suitability of an oil is best judged by its practical performance. Such service tests are necessarily expensive and time-consuming, and, to obtain reliable data, extensive tests with subsequent statistical analysis are desirable. Hence many efforts have been made towards designing suitable pieces of laboratory apparatus which can be used to simulate service conditions, while giving results in a shorter period of time. Details of many tests used for the evaluation of gear oils, cutting oils, aviation gas turbine oils, and hydraulic oils are given.

R. H.

2916. Modern techniques in petroleum testing. IX. Mechanical tests for lubricating greases. S. R. Pethrick. *I.P. Review*, 1952, **6**, 139.—The practical performance of a grease depends on its initial flow properties and on the extent to which the properties are retained during operation. Although at the moment simulated performance tests are necessary to assess quality, it is possible that at a future date a combination of rheological and chemical tests will be sufficient. A number of the more widely known mechanical tests are described, and it is pointed out that the emphasis upon this kind of testing tends to make the procedure expensive. Mechanical working tests are mentioned, and the performance of different types of grease indicated. High temp tests are described in relationship to various specifications. Other tests include the wheel bearing lubricant tester, water resistance tests, the low temp torque test (for aircraft greases), tests for fretting corrosion (arising from vibration and oscillation), and gear wear tests. R. H.

2917. Calibrating wavelengths in the region from 0·6 to 2·6 microns. N. Acquista and E. K. Pyler. *J. Res. Nat. Bur. Stand.*, July 1952, **49** (1), 13–16.—With a view to obtaining additional calibration points for prism instruments, the wavelengths of twenty absorption bands have been determined on a grating spectrometer in the region from 0·6 to 2·6 μ. The bands selected for calibration are parts of the absorption spectra of didymium glass, carbon disulphide, 1 : 2 : 4-trichlorobenzene, and polystyrene. Five graphs of the measured spectra are included, and the calibrated wavelengths are marked on the bands in order to facilitate identification. Several emission lines of krypton are recorded. W. H. C.

2918. New analyser breaks bottleneck in F.C.C. operation. J. L. Serrill. *Oil Gas J.*, 1.9.52, **51** (17), 84.—Use of an infra-red type carbon monoxide analyser of simple design and rugged construction enables a faster carbon burning rate during regeneration of fluid catalytic cracking units. Manual control of the analyser is essential.

Instrument maintenance men can look after the analyser and sampling system.

G. A. C.

2919. Refiner's notebook. M. R. Beychok. *Oil Gas J.*, 8.9.52, **51** (18), 135.—No. 137 of the Refiner's notebook gives methods for determinations of pure dry naphthenic acid and neutral oil content of the acid in spent caustics. G. A. C.

2920. High shear method of rating brushability of paints. W. K. Asbeck, D. D. Laiderman, and M. V. Loo. *J. Coll. Sci.*, 1952, **7**, 306–15.—A rotational viscometer is described which operates at high shear velocities. The centering of the inner cyl is automatic, clearances of 100 μ are easily maintained, and shear velocities of the order 20,000 sec^{-1} are attainable. At smaller clearances these velocities may be increased substantially without excessive temp rises.

Lub oils exhibit linear graphs of shearing stress *v* shearing strain up to 16,700 sec^{-1}, the highest shearing velocity measured. H. C. E.

Crude Oil

2921. Italian crude oil analyses. G. C. Facca, G. Roberti, and E. Sommariva. *Proc. 3rd World Petrol. Congr.*, 1951, **1**, 359–89.—The scope of this paper is to compare various crude oils produced throughout Italy and Sicily, and to ascertain if relations exist between the chemical and physical characteristics of the oils and the horizons or depths from which they have been derived.

Complete analyses have been carried out according to the U.S. Bureau of Mines method, and the data giving the general character for each oil are set out in twenty-six tables. In a summary at the foot of each table approx percentages of gasoline, kerosine, and other products are calculated. G. S. S.

Gas

2922. Engineering problems related to Alberta natural gas. G. W. Govier. *Engineering J.*, Aug. 1952, **35** (8), 823–6, 841.—The important engineering and economic aspects of the development and marketing of natural gas are discussed with respect to: the reserves and how they are calculated; delivery characteristics of the field and how deliverability is computed; the various types and composition of natural gases, the methods of processing for removal of undesirable constituents in order to obtain a marketable product; domestic, commercial, and industrial markets, demands, loan factors, and peak loads, and how these are affected by temp; and the extra demand that will be made on the completion of the Edmonton petrochemical plant in 1952. The general principles governing the design of pipelines are outlined, and the cost of transportation is determined. W. H. C.

2923. Italian natural gas analysis. E. Pera. *Proc. 3rd World Petrol. Congr.*, 1951, **1**, 267–85.—For the past twenty-five years the Azienda General Italiana Petroli has given much attention to natural gas occurrences and to gas originating from research wells and those already in production. Physical data and chemical analyses accompany the report, and the results are given in tabular form occupying eighteen pages. The object of the work was not only to determine the composition of the gas, but also to establish whether it had any connexion with oilfields. All gas samples were therefore tested for higher hydrocarbons by the Jaeger method. G. S. S.

2924. Patent. U.S.P. 2,589,810 (29.3.48; 18.3.52). W. H. Holcroft, assr to Holcroft & Co. Gaseous hydrocarbon fuel is burnt, water is removed from the products, and the products mixed with a further quantity of the fuel and subjected to the action of a catalyst which has been indirectly heated by the first combustion. J. M. S.

Engine Fuels

2925. Liquefied automotive fuel gas. Draft German standards. *Erdöl u. Kohle*, 1952, **5**, 427–9, 490–2.—Test of quality standard, DIN 51620, (cf Abs. 2455) is reproduced; requirements additional to those previously mentioned are C_4 75% max (summer) 70% max (winter), total S 400 mg/kg max, ammonia nil, resins nil, oil 50 mg/kg max, water not visible at $> -30°$ C. Following are also given in full: DIN

51616, determination of v.p. and d (bomb method at 40° C for v.p., $\bar{d}$ calculated from wt of liquid gas required to fill bomb); DIN 51615, determination of H_2S (absorption in NaOH, pptn as CdS, decomp of latter with I, and titration of excess I; accuracy $\pm 0{\cdot}02$ mg H_2S/kg); DIN 51613, determination of elementary S (residue left after evaporation of liquefied gas is treated with Hg, HgS formed is decomposed with HCl and evolved H_2S determined iodometrically; accuracy $\pm 0{\cdot}2$ mg S/kg); DIN 51617, determination of total S (gas is burnt, SO_2 formed oxidized by H_2O_2, and S determined gravimetrically as $BaSO_4$; accuracy ± 4 mg S/kg); DIN 51614, determination of ammonia, water, oil, and resins (NH_3 test qualitative only, gas passed through H_2SO_4, latter neutralized with NaOH and mixture tested with Nessler reagent); water is tested for qualitatively (appearance of gas in the liquid state); for determination of oil and resins gas is vaporized in flask to outlet of which cotton wool filter is fitted, wt of residue in flask + residue from benzene washings of filter is determined and = elementary S + oil + resins. Separation of oil and resins is by dissolving total residue in n-heptane and adsorbing resins on bleaching clay, latter is washed with heptane till free from oil, heptane solution and washings united, solvent evaporated off, giving oil; resins by difference; accuracy ± 5 mg/kg. V. B.

2926. Patents. U.S.P. 2,587,581 (10.5.48; 4.3.52). S. Shappirio. Fuels and lubricants containing a sulphazide of the formula $RNHNHSO_2R'$, where R and R′ are alkyl or aryl groups.

U.S.P. 2,588,713 (3.1.50; 4.3.52). R. G. Elliott and J. A. Bennett. Fuel-mixture vaporizer for gas engines.

U.S.P. 2,589,979 (1.9.49; 18.3.52). B. R. Strickland, assr to Standard Oil Development Co. Gasoline containing N,N′-di-*sec*-butyl *p*-phenylenediamine and *p*-dioxan. J. M. S.

Gas Oil and Fuel Oil

2927. Patents. U.S.P. 2,587,700 (26.4.47; 4.3.52). H. Cowan, assr to The Babcock & Wilcox Co. Liquid fuel burner.

U.S.P. 2,588,423 (21.7.47; 11.3.52). R. E. Simmons, assr to Denver Fire Clay Co. Oil burner with co-ordinated air and oil valves.

U.S.P. 2,590,063 (7.2.47; 18.3.52). W. D. Bailey. Rotary reaction nozzle fuel burner.

U.S.P. 2,590,111–12 (13.1.49; 25.3.52). C. D. MacCracken and C. W. Wood, assrs to Jet-Heet Inc. Fuel oil control system and temperature responsive throttling device for use in the same. The flow of fuel is kept constant despite visc changes due to changes in temp. J. M. S.

Lubricants

2928. Lubricant classification. C. A. Bailey. *Lubr. Engng*, June 1952, **8** (3), 125–8.—The importance of satisfactory classification of industrial lubricants is stressed. The SAE classification for crankcase oils and the NLGI grease classification are briefly reviewed, and the classification devised by the U.S. Steel Co. covering mineral oils, greases, and special products is described in some detail. J. G. H.

2929. Let service choose diesel lubricants. C. G. A. Rosen. *Gas Oil Pwr*, 1952, **47**, 161–4.—A review of the ways in which lubricants are chosen for use in particular engines, based on American practice.

Originally engine manufacturers listed recommended brands of oil based on *ad hoc* experience. Later, chemical and physical tests such as carbon residue, colour, neutralization value, visc, and V.I. were used to designate oils for particular purposes, and this led to the introduction of solvent refined oils. These gave rise to engine problems such as corrosion, ring sticking, etc., and individual manufacturers then set up laboratory and field tests which oils must pass before recommendation.

Author presents a chart in which the severity of engine conditions (divided into five

sections, varying from lightly loaded petrol engines to heavily loaded diesel engines) is plotted against hours of service. Oils can then be represented by straight lines of negative slope, and the suitability of a particular oil for a particular type of engine can be immediately deduced.

It is stressed that classification of oils should be on service requirements and not on any single property of the oil, and co-operation between engine manufacturers and oil refiners is urged. H. C. E.

2930. Fretting corrosion studies with a modified Fafnir machine. T. G. Roehner and E. L. Armstrong. *Institute Spokesman*, June 1952, **16** (3), 8–15.—The incidence of fretting corrosion under a variety of conditions is remarked, and the use of modifications of the Fafnir Friction Oxidation Machine for the evaluation of lubricating greases in respect to their ability to minimize or prevent fretting corrosion is noted. A detailed account of operations with a modified Fafnir machine incorporating oscillating thrust test bearings testing a number of greases is presented, and from the results obtained it is concluded that increasing the arc and frequency of oscillation of the bearings tends to promote fretting corrosion, and that before differences in the quality of lubricating greases can be realized they must have the proper consistency to permit renewal of the lubricating film. J. G. H.

2931. Research and development at Fulmer Hall. Anon. *Scientific Lubrication*, July 1952, **4** (7), 12–14.—A description of the new laboratories and test equipment of Monsanto Chemicals. Includes notes on the engine testing of additives, using Petter, Chevrolet, and Caterpillar engines. J. G. H.

2932. Grease lubrication of ball bearings. L. D. Cobb. *Lubr. Engng*, June 1952, **8** (3), 120–4.—The development of grease-lubricated sealed bearings is briefly sketched, and procedure for the evaluation of new greases is described in detail, with extended descriptions of the test equipment employed. The effect of grease volume on bearing life is discussed, together with the use of radioactive methods for the study of the mechanics of grease lubrication. Details are given of recently developed high-speed bearings which will constitute a challenge to the grease makers to produce adequate lubricants. J. G. H.

2933. Maintenance lubrication of ball and roller bearings. R. L. Wheeler. *Institute Spokesman*, May 1952, **16** (2), 20–32.—The importance of due consideration being given to lubrication details in the design of new machinery is emphasized, and the functional requirements of anti-friction bearings are enumerated and considered in some detail. Bases for the selection of the most suitable grease for the purpose are indicated, and relevant characteristics and tests are outlined, together with the properties of multi-purpose lubricants and special greases. The significance of consistency, quantity and frequency of application, cleaning anti-friction bearings, and the causes and prevention of bearing failures are also considered. J. G. H.

2934. Running test experiences with porous oil-retaining bronze bearings. Anon. *Scientific Lubrication*, June 1952, **4** (6), 12–15.—Details are presented of the testing equipment at the new Bound Brook Bearings factory at Lichfield; accelerated testing and friction measuring machines are described, and the effect of additives in the lubricant on test results is noted. J. G. H.

2935. Oil-free steam cylinder lubrication. H. P. Jost. *Scientific Lubrication*, June 1952, **4** (6), 22–5.—The disadvantages of oil as a lubricant for steam cyl are indicated, and the lubricating properties of graphite are enumerated. Difficulties encountered in the application of graphite are pointed out, and typical application equipment is described and illustrated. The advantages and limitations of oil-free lubrication are tabulated, and the urgency of following equipment makers' instructions is emphasized. J. G. H.

2936. Influence of point of application of cutting oil on tool life. W. E. Lauterbach. *Lubr. Engng*, June 1952, **8** (3), 135–6.—Details are presented of a series of tool-life tests conducted on a tool-room lathe under A.S.A. test conditions to determine the

influence of the point of application on the life of a single point tool in a lathe-turning operation. Results obtained indicate that the cutting oil performs its functions most effectively when the oil is directed up into the clearance crevice than when it is directed down over the tool and chip. J. G. H.

2937. Practical lubrication of ammonia compressors. R. W. Tong. *Scientific Lubrication*, June 1952, **4** (6), 16–21.—Practical notes on the maintenance of ammonia compressors, where no laboratory facilities are available. Points dealt with include detection of water leaks, situation, installation, and the lubrication and maintenance of main components. J. G. H.

2938. Animal and vegetable oils . . . fats and waxes. Pt 3. Identification. C. Griffiths. *Scientific Lubrication*, July 1952, **4** (7), 22–5.—The difficulties attendant on the exact identification of individual oils, fats, and waxes are noted, and tabulated details of tests for drying and semi-drying oils, non-drying vegetable and animal oils, marine animal oils, vegetable and animal fats and waxes are presented. Characteristic properties of the various groups are noted, and the effect of blowing on properties is indicated. J. G. H.

2939. Fine structure and rheological properties of lithium soap-oil dispersions. B. W. Hotten and D. H. Birdsall. *J. Coll. Sci.*, 1952, **7**, 284–94.—The effect of variation of soap anion composition, oil composition, and dispersion procedure on the soap particle structure and rheological properties of lithium soap grease is described. The soap concentration was 12%, and the anions studied include saturated carboxylates (C_{14}-C_{18}), unsaturated fatty anions, and 12-hydroxystearate. The oil is mainly a 360 S.S.U. (100° F) blend, but diesters, polyethers, and polysiloxanes are also used. Electron micrographs (8000 ×) of the dispersed soap particles are presented and described, and the shape and size of the particles is correlated with the texture and consistency of the grease. It is found that particle size increases with increasing cooling time of hot solutions, and the ratio of particle surface area to vol is a direct determinant of gelling power.

When the grease flows through a tube, rod-like particles of dispersed soap (Li palmitate) are highly oriented at the walls parallel with the line of flow and unoriented at the centre of the tube. H. C. E.

2940. Patents. U.S.P. 2,587,621 (31.3.48; 4.3.52). E. C. Hughes and J. D. Bartleson, assrs to The Standard Oil Co. Lubricating oil additives comprising the reaction product of an organic compound and a phosphorus sulphide are improved by solvent extraction.

U.S.P. 2,587,642 (3.2.48; 4.3.52). J. M. Musselman and H. P. Lankelma, assrs to The Standard Oil Co. Mineral lubricating oils and greases containing a reaction product of an unsubstituted fatty acid having an iodine value ≥ 70 and P_2S_5 or P_4S_9.

U.S.P. 2,588,194 (22.12.50; 4.3.52). E. Arundale and J. P. Thorn, assrs to Standard Oil Development Co. Synthetic lubricant of the diester type.

U.S.P. 2,588,273 (2.8.50; 4.3.52). A. J. Morway and P. V. Smith, assrs to Standard Oil Development Co. Lubricating grease containing at least 25 wt-% of a sulphur-containing ester of the formula RZOCYCOZR, wherein Y is a divalent aliphatic hydrocarbon radical of from 2 to 8 carbon atoms and which may contain a thio ether linkage, R is an aliphatic hydrocarbon radical of from 8 to 20 carbon atoms, and Z is an oxygen or sulphur atom, and thickened by means of a lithium soap of a saturated fatty acid.

U.S.P. 2,588,279 (2.2.50; 4.3.52). R. O'Halloran, assr to Standard Oil Development Co. Blended grease comprising 95 to 50 wt-% of Grease A and 5 to 50 wt-% of Grease B. Grease A is formed from a mixture of sodium and barium soaps of saturated fatty acids, the mol ratio of sodium soap to barium soap being from 1 to 1 to 25 to 1. Grease B is formed from a mixture of a sodium soap of a high mol. wt. saturated fatty acid and a sodium salt of a low mol. wt. carboxylic acid, the mol ratio of soap to salt being from 1 to 1 to 4 to 1.

U.S.P. 2,588,280 (26.8.49; 4.3.52). R. O'Halloran and J. J. Kolfenbach, assrs to Standard Oil Development Co. Lubricating grease consisting of a lubricating oil thickened with 10 to 20% of a mixture of sodium and barium salts of a mixture of saturated aliphatic acids containing from 10 to 90 wt-% of an acid in the C_{16} to C_{22} range and from 10 to 30 wt-% of an acid having 4 less carbon atoms than the predominating acid.

U.S.P. 2,588,326 (28.7.49; 4.3.52). A. B. Odgen, R. A. Butcosk, and R. C. Williams, assrs to Socony-Vacuum Oil Co. Inc. The cooking of a mineral lubricating oil with a fatty acid soap to produce a block grease is carried out in presence of a small amount of an ester of a dibasic carboxylic acid with an aliphatic alcohol.

U.S.P. 2,588,556 (16.5.49; 11.3.52). R. J. Moore and W. Saarni, assrs to Shell Development Co. Method of making greases from alkali metal soaps, alkaline earth metal soaps, or mixtures thereof, by forming a slurry of the soap and lubricating oil, heating to 180° to 250° C to form a homogeneous non-crystalline mixture, cooling to gelation, and heat-treating at 100° to 172° C.

U.S.P. 2,588,625 (15.3.45; 11.3.52). W. E. Ferner, G. Alexander, J. Robinson, and W. E. Streeter, assrs to Aluminum Co. of America. Forging lubricant comprising an aqueous slurry of finely divided solid mineral lubricating material, an organic adhesive and an inorganic water-soluble salt.

U.S.P. 2,589,317 (10.1.45; 18.3.52). D. W. Young and S. G. Gallo, assrs to Standard Oil Development Co. Foaming of hydrocarbon oils is prevented by addition of a solid gel repolymerization product of a liquid hydrocarbon–silicone polymer.

U.S.P. 2,589,326 (21.12.49; 18.3.52). E. A. Oberright, assr to Socony-Vacuum Oil Co. Inc. Minerals lubricating oil containing a product made by reacting phosphorus pentasulphide with a triester of phosphorous acid containing at least one alkenyl radical.

U.S.P. 2,589,582 (12.8.49; 18.3.52). P. Strughold and J. F. May. Lubricant stick suitable for lubricating locomotive wheels comprises 80 to 90% amorphous graphite and 20 to 10% " bakelite " compounded under pressure.

U.S.P. 2,589,973 (1.11.49; 18.3.52). P. V. Smith and A. J. Morway, assrs to Standard Oil Development Co. Lubricating grease comprising a lubricating oil thickened with 3 to 40 wt-% of metal soaps of aliphatic carboxylic acids, at least a third of the soaps being a soap of an acid of the formula R_1CHR_2COOH, wherein

$$OR_3OH$$

R_1 and R_2 are alkyl groups of 3 to 12 carbon atoms and R_3 is an alkyl group of 2 to 6 carbon atoms.

U.S.P. 2,590,451 (9.8.47; 25.3.52). G. L. Perry, assr to Shell Development Co. Metal fabricating lubricant consisting of microcrystalline slop wax, 20 to 40 wt-% gas oil and 1 to 5 wt-% of a polyalkylene glycol diester.

U.S.P. 2,590,786 (19.5.50; 25.3.52). J. W. Nelson, assr to Sinclair Refining Co. A grease comprising a lubricating oil thickened by a mixture of high mol. wt. microcrystalline wax acids produced by oxidation of such wax.

U.S.P. 2,590,801 (19.5.50; 25.3.52). J. W. Teter and J. W. Nelson, assrs to Sinclair Refining Co. As in U.S.P. 2,590,786, but the soaps of the wax acids are used.

J. M. S.

Bitumen, Asphalt, and Tar

2941. Bitumen and its uses. A. B. C. Licence. *I.P. Review*, 1952, **6**, 237.—All the various aspects of bitumen are most usefully summarized. The confusion which exists due to geographical differences in terminology is explained. Various forms of naturally occurring bitumen (with filler) and the production of bitumen from mineral oil are described. The differences between distilled and blown bitumens are explained, and the significance of the differences in properties of these types related to uses. The manufacture and uses of derivatives of bitumen, *i.e.*, bitumen emulsions (including clay stabilized emulsions), cutbacks, and filled bitumens are mentioned. The main consistency tests by which bitumens are graded (*i.e.*, Soft Pt and Pen) are explained.

Special detail is given to the uses of bitumen (and cutbacks and emulsions) in the road industry, in the form of macadam and as surface dressing. Other uses mentioned are thermal and electrical insulation, water-proofing (as paper and roofing felt), and protective work (*i.e.*, as paint). R. H.

2942. Some applications of asphalt to hydraulic works. H. A. Ferguson. *Ingenieur*, 1.8.52, **64** (31), B123–30.—Sand–bitumen mixtures need a min of 5% bitumen to ensure complete enrobing of the sand particles, but for hydraulic applications, bitumen contents of 15 to 20% are considered necessary. Coatings of seashore embankments require different properties and methods of application for the submerged, exposed, and tidal zones of the embankment surface. Destruction of the coating by vegetation and animal pests and means to avoid it are dealt with. Seventeen photographs illustrating different applications and defects are discussed extensively. G. F. T. C.

Special Hydrocarbon Products

2943. Patents. U.S.P. 2,587,577 (27.3.48; 4.3.52). V. N. Ipatieff and H. Pines, assrs to Universal Oil Products Co. Arylindans are made by reacting a branched chain alcohol and a *p*-disubstituted benzene hydrocarbon, one of the substituents of which is a saturated hydrocarbon group of at least 3 carbon atoms with a hydrogen atom on the carbon atom attached to the benzene ring. The reaction is effected at −30° to 100° C in presence of mineral acid.

U.S.P. 2,587,588 (24.12.47; 4.3.52). D. A. Berry, assr to Diamond Alkali Co. Drying oils are made by dehydrochlorinating a chlorinated paraffin having between 18 and 36 carbon atoms and an average of between 4 and 10 chlorine atoms per mol until it has an average of less than one chlorine atom per mol. The dehydrochlorination is effected by an alkali metal hydroxide in a dihydric alcohol or ether in presence of titanium or zirconium dioxide.

U.S.P. 2,587,777 (30.4.37; 4.3.52). C. W. Smith, assr to Detrex Corpn. Cleaning and rustproofing composition comprising kerosine, triethanolamine oleate, cobalt naphthenate, and water.

U.S.P. 2,587,957 (10.8.45; 4.3.52). O. W. Bauer and J. W. Teter, assrs to Sinclair Refining Co. Insect repellent sheet material containing a chlorobutyroamide.

U.S.P. 2,588,318 (7.2.49; 4.3.52). P. G. Benignus, assr to Monsanto Chemical Co. Water emulsifiable soil poison concentrate comprising 25 to 45 parts by wt of a chlorinated diphenyl, 25 to 45 parts by wt of trichlorobenzene, 7 to 13 parts by wt of pentachlorophenol, 2·5 to 4·5 parts by wt of *iso*propyl alcohol, 10 to 20 parts by wt of an aromatic oil boiling between 170° and 570° F, 0·5 to 1·5 parts by wt of a non-resinous condensation product of ethylene oxide and abietic acid or a derivative thereof, and 0·25 to 1·25 parts by wt of an organic sulphate or sulphonate.

U.S.P. 2,588,407 (29.12.48; 11.3.52). M. S. Newman and B. J. Magerlein, assrs to U.S.A. as represented by the Secretary of the Army. Insect repellant composition comprising 4-hydroxymethyl-2-methyl-2-phenyl-1 : 3-dioxolane in an inert organic carrier.

U.S.P. 2,588,428 (2.4.45; 11.3.52). W. D. Stewart and J. H. Standen, assrs to The B.F. Goodrich Co. The addition products of an aliphatic substituted zinc dithiocarbamate and a primary or secondary amine are pesticides.

U.S.P. 2,588,812 (27.6.50; 11.3.52). P. F. Dougherty, assrs to Sun Oil Co. Flat, elongated cakes of wax with uniform ridges on opposite faces to enable the wax cakes to be packed with min contact of their surfaces.

U.S.P. 2,588,969 (26.11.49; 11.3.52). J. B. Dickey and H. W. Coover, assrs to Eastman Kodak Co. Acylaminoacrylates and acylaminocrotonates are insecticides.

U.S.P. 2,588,997 (20.12.49; 11.3.52). E. B. Towne and H. M. Hill, assrs to Eastman Kodak Co. Insecticidal composition comprising 2 : 3 : 4 : 4 : 5 : 5-hexachloro-2-*cyclo*pentenone and a refined petroleum distillate.

U.S.P. 2,589,150 (9.4.46; 11.3.52). V. Schneider, assr to Phillips Petroleum Co. Halogenated Gray tower polymer fractions are insecticides.

U.S.P. 2,590,659 (24.6.49; 25.3.52). B. G. Skalkeas, assr to Monsanto Chemical Co. Textile treating composition comprising an alkaline reacting silica aquasol containing 5 to 45 wt-% colloidal silica, 15 to 75 wt-%, based on the silica, of a water-soluble or water-emulsifiable lubricating oil and 15 to 75 wt-%, based on the silica, of an organic hygroscopic agent.

U.S.P. 2,590,818 (15.8.49; 25.3.52). O. H. Hammer, assr to The Dow Chemical Co. Miticide comprising 1 to 40 parts of a petroleum oil, having an unsulphonated residue of $<50\%$, for each part of 4′-chlorophenyl-4-chlorobenzene sulphonate.

J. M. S.

Derived Chemical Products

2944. Sulphur from oil wells. P. W. Sherwood. *Chim. et Ind.*, 1952, **67**, 931–2.—Original form of Claus reaction ($2H_2S + O_2 = 2H_2O + 2S + 48250$ cal) is too exothermic for practical use, since low space velocities would have to be used. Present processes employ the non-catalysed reaction $H_2S + 1\frac{1}{2}O_2 = H_2O + SO_2 + 56{,}500$ cal (waste heat being utilized), followed by the bauxite-catalysed reaction $2H_2S + SO_2 = 3S + 2H_2O + 15700$ cal; heat-generation of catalysed stage is thus reduced, and high space velocities are permissible. 97% yields of S can be attained. Peculiar visc/temp relationship of S requires temp of latter to be kept at 115° to 165° C. Various possible process modifications are briefly described. V. B.

2945. Patents. U.S.P. 2,587,576 (2.12.50; 4.3.52). E. Field and B. L. Hill, assrs to Standard Oil Co. Higher alcohols are prepared from aldehydes having 2 to 4 carbon atoms by reacting the aldehyde with carbon monoxide and hydrogen in presence of cobalt carbonyl or hydrocarbonyl at 120° to 200° C under 1000 to 10,000 p.s.i. pressure.

U.S.P. 2,587,666 (17.6.50; 4.3.52). W. G. Toland, assr to California Research Corpn. Products obtained by the partial oxidation of alkyl aromatic hydrocarbons are oxidized by contact at above 550° F with an aqueous mixture of an alkali metal or alkaline earth metal hydroxide or a salt thereof with a weak inorganic acid and an inorganic sulphurous material. The products are aromatic carboxylic acids.

U.S.P. 2,587,753 (26.4.49; 4.3.52). B. O'Connor and F. G. Pearce, assrs to Stanolind Oil and Gas Co. Crude alcohols are purified by countercurrent contact with a borate ester of another alcohol under extractive distillation conditions. Radical interchange takes place.

U.S.P. 2,588,268 (22.9.48; 4.3.52). K. K. Mercer and W. E. Catterall, assrs to Standard Oil Development Co. Process for dehydrating *iso*phorone fatty acid extract.

U.S.P. 2,588,388 (16.12.49; 11.3.52). D. C. Hull, assr to Eastman Kodak Co. Oxidation of methyl *cyclo*hexane to *cyclo*hexanoic acid using an acetaldehyde activated cobalt acetate catalyst solution in acetic acid.

U.S.P. 2,588,446 (9.6.49; 11.3.52). S. W. Wilson, assr to Standard Oil Development Co. Crude aqueous *iso*propanol, prepared by the sulphuric acid-catalysed hydration of propylene, is purified by rendering it basic, distilling off the low-boiling impurities and *iso*propanol, and redistilling the distillate to remove the low-boiling impurities, leaving the highly refined *iso*propanol as bottoms.

U.S.P. 2,588,826 (27.9.45; 11.3.52). R. C. Goodwin, assr to Phillips Petroleum Co. Drying oils are prepared from unsaturated polymers obtained in the clay treating of cracked gasoline by treatment with an aldehyde in presence of an acid condensation catalyst at 30° to 220° F.

U.S.P. 2,588,867 (25.10.48; 11.3.52). E. K. Morris, assr to The Dow Chemical Co. Vapour mixture of polychloroalkanes and chlorine is pyrolysed at 300° to 650° C in presence of a catalytic proportion of bromine vapour.

U.S.P. 2,588,899 (Netherlands 2.9.49; 11.3.52). H. J. Voorthuis and C. P. Van Dijk, assrs to Shell Development Co. High mol. wt. halogenated materials are stabilized by addition of an acid-neutralizing compound, an oxidation inhibitor and a

compound of the formula RNHCONHR, wherein R is a hydrogen atom or a phenyl group substituted by a polar group, at least one of the R's being such a phenyl group.

U.S.P. 2,589,112 (30.10.48; 11.3.52). J. E. Moise, W. D. Luening, and W. G. Daroux, assrs to Standard Oil Development Co. Process for preparing acetic anhydride involving the pyrolysis of acetone to ketene and reaction of ketene with acetic acid.

U.S.P. 2,589,689 (12.11.49; 18.3.52). L. J. Governale and C. M. Neher, assrs to Ethyl Corpn. Ethane is chlorinated in gaseous phase under influence of actinic light, droplets of hydrochloric acid being distributed throughout the reaction zone in an amount sufficient to remove the heat of reaction.

U.S.P. 2,590,059 (26.3.49; 18.3.52). De Loss E. Winkler, assr to Shell Development Co. High mol. wt. halogenated organic substances are stabilized with a glycidyl ether and an alkaline earth metal or cadmium salt of a carboxylic acid.

U.S.P. 2,590,613 (24.5.48; 25.3.52). J. E. Hanson, assr to California Research Corpn. Detergent composition comprising a water-soluble salt of a celluronic acid and an alkaryl sulphonate detergent.

U.S.P. 2,590,810 (5.8.50; 25.3.52). R. B. Young, assr to General Electric Co. Vinyl chloride is made by passing acetylene and hydrogen chloride in the vapour phase over a copper salt adsorbed on a carbon adsorbent. J. M. S.

Coal, Shale, and Peat

2946. Methane and coal. A. Egerton. *Nature*, 1952, **170**, 93–7.—Study of the structure of coal indicates that it may contain colloidal particles of dia *ca* 3×10^{-6} cm with a very fine pore structure between them. Coal dust can absorb *ca* twenty times its vol of CH_4 at 10 atm pressure, but the gas can leak out through the fine pores only slowly. An average absorption of 10 vol of gas corresponds to $<1\%$ wt.

Theories of the formation of CH_4 in coal are discussed. It is thought that coal should contain *ca* 10% wt CH_4, but since the average value is only *ca* 1% wt, it is probable that the gas gradually diffuses out of the coal, sometimes into porous deposits, when it is lost, and sometimes to a region sealed by impervious rock, when it can be collected by tapping.

Mine ventilation entails the pumping of 6 tons of air per ton of coal mined, and if the average CH_4 concentration is 0·25% the total amount of CH_4 removed is equivalent to 3 to 4 million tons of coal per year. This gas can be utilized either by mine drainage or by using the ventilation air as a source of energy. Mine drainage from boreholes yields a gas which can be compressed and used for transport, cracked for use as town's gas, or employed as a raw material in the chemical industry.

Research designed to burn ventilation air (as for instance in a gas turbine) containing *ca* 1% CH_4 showed that at a gas flow of 0·126 cu. ft/min and temp 1020° C about 10% of the CH_4 is burnt in the first 4·5 cm of the furnace and the remainder in the next 2 cm; corresponding times are 2·5 and 1 millisec respectively. The combustion temp is unaffected by pressure increases up to 2·5 atm, but is reduced by addition of oxygen, by reducing the CH_4 concentration to 0·5%, and by adding 0·125% hydrocarbons or hydrogen. It is found that combustion of CH_4 is a two-stage process; firstly oxidation to CO and then to CO_2; the second process is inhibited by the first, and is not completed in the time available (3·5 millisec) unless the temp is *ca* 1050° C.

On the basis of these results a gas turbine plant was set up. The air is preheated to 450° C in a heat exchanger and then goes to a booster, where the CH_4 is burned, increasing the temp to 1150° C. In leaving the booster the gases heat the incoming air by 450° C, and are themselves cooled to 700° C before going to the turbine. The waste gases are fed back to the heat exchanger.

Article closes with a section on methane as a fuel for I.C. engines and the economic possibilities of its transport in the liquid state. H. C. E.

2947. Patents. U.S.P. 2,588,075 (18.12.45; 4.3.52). F. T. Barr, B. E. Roetheli, and W. G. Scharmann, assrs to Standard Oil Development Co. Methods of gasifying solid carbonaceous fuels using fluidized bed technique.

U.S.P. 2,588,076 (28.12.45; 4.3.52). E. J. Gohr, assr to Standard Oil Development Co. Method of gasifying solid carbonaceous fuels using fluidized bed technique.

U.S.P. 2,589,109 (29.12.45; 11.3.52). H. Z. Martin and F. T. Barr, assrs to Standard Oil Development Co. Fluidized distillation of shale.

U.S.P. 2,590,733 (10.8.48; 25.3.52). A. L. Stillman, assr to Fuel Research Corpn. Stable suspensions of coal particles are made by mixing 15 to 25 wt-% of coal particles $>0{\cdot}5\ \mu$ with a hydrocarbon liquid and, when the Brownian movement is sufficiently intense to support larger size particles, dispersing coal particles, $>0{\cdot}5\ \mu$ but >200 mesh, until the coal forms 30 to 60 wt-% of the mixture. J. M. S.

Miscellaneous Products

2948. Design of a continuous cold rubber process. M. W. Larsen. *Chem. Engng Prog.*, May 1951, **47** (5), 270–4.—The preparation of cold rubber as compared with regular GR-S "hot" rubber is described, with details of plant for batch and continuous production. The selection and operation of the necessary refrigeration equipment is discussed, and advantages of the continuous process are enumerated. J. G. H.

2949. Patents. U.S.P. 2,587,791 (27.6.50; 4.3.52). R. B. Thompson and H. S. Bloch, assrs to Universal Oil Products Co. Resinous copolymers of an aromatic monofulvene and a mono- or di-olefin.

U.S.P. 2,588,512 (13.5.50; 11.3.52). H. R. Gamrath and W. E. Weesner, assrs to Monsanto Chemical Co. Vinyl chloride polymers are plasticized with alkyl benzyl tetrachlorophthalates.

U.S.P. 2,588,890 (5.4.48; 11.3.52). E. C. Shokal and P. A. Devlin, assrs to Shell Development Co. Drying esters are made by heating a mixture of allyl alcohol and styrene at 100° to 200° C while passing oxygen through it and esterifying the copolymer with an unsaturated fatty acid.

U.S.P. 2,589,069 (4.6.48; 11.3.52). E. V. Fasce, assr to Standard Oil Development Co. Hard resins are prepared from oily olefin polymers containing cyclic diolefins by reaction with a dibasic organic acid anhydride in presence of aluminium chloride at 150° to 250° F.

U.S.P. 2,589,151 (12.9.46; 11.3.52). G. Serniuk, assr to Standard Oil Development Co. A copolymer of 1 : 3-butadiene and styrene is dissolved in benzene and the solution mixed with thioglycolic acid in presence of air to form a hydrocarbon-insoluble vulcanizable copolymer adduct.

U.S.P. 2,589,190 (29.7.47; 11.3.52). J. E. Hanson, assr to California Research Corpn. Detergent composition comprising an alkaryl sulphonate detergent and an alkali metal salt of a celluronic acid.

U.S.P. 2,589,237 (25.8.50; 18.3.52). E. K. Ellingboe, assr to E.I. du Pont de Nemours and Co. Copolymer of vinyl chloride and allyl glycidyl ether. J. M. S.

Corrosion

2950. Corrosion control. Anon. *Oil Gas J.*, 11.8.52, **51** (14), 153.—Pt 9 of this series continues with protection of storage tanks, and discusses gunite, cathodic protection, and installation of temporary patches. G. A. C.

2951. How dehydration curtails corrosion in pipelines. R. P. Dougherty. *Oil Gas J.*, 1.9.52, **51** (17), 94.—Control methods for operation of a Strouds dehydrator with a daily capacity of 20,000 brl are given, using activated alumina as desiccant. Use results in drastic reduction of internal corrosion of pipelines, at a cost of $0.68/1000 brl. Flow sheets are given. G. A. C.

2952. Aluminium alloys for offshore pipelines. E. T. Wanderer and S. O. Sprowls. *Corrosion*, 1952, **8** (7), 227–33.—An aluminium pipeline has been installed in an offshore pipeline system carrying natural gas. It is completely unprotected, and after

twenty months' service exterior and interior surfaces are in excellent condition. Care must be taken not to overstress welds during construction of aluminium pipelines.
K. G. B.

2953. Some corrosion experiences with aluminium crude oil lines. A. Ellis. *Corrosion*, 1952, **8** (8), 289–91.—Aluminium pipelines carrying sour crude suffered internal pitting and scaling along the bottom. The pitting was worst in the annealed areas near welds, and was aggravated by iron sulphide scale from adjacent steel pipes. Replacement of aluminium pipes was necessary owing to internal corrosion after twenty-four to thirty-eight months' service. External corrosion depended upon the environment. No external corrosion was found after 3½ years in a salt marsh, but pitting occurred in sixteen months in an acidic soil. K. G. B.

2954. A hydrogen evolution method for evaluation of corrosion inhibitors for oil wells. W. R. Scott and G. H. Rohrback. *Corrosion*, 1952, **8** (7), 234–40.—The corrosion of a steel coupon immersed in continually flowing carbonic acid/brine solution is measured by determining the rate of production of hydrogen, either in a gas burette system or by a thermal conductivity method. The effect of inhibitors is studied by injecting them into the liquid stream just prior to passage over the steel. The method provides a rapid and convenient means for screening a large number of potential inhibitors. It is readily adaptable to investigate corrosion by other aqueous media. K. G. B.

2955. Patents. U.S.P. 2,857,955 (28.4.47; 4.3.52). E. R. Barnum, assr to Shell Development Co. Corrosion inhibiting composition comprising a liquid hydrocarbon and an oxazoline salt of ricinoleic acid.

U.S.P. 2,588,412 (16.9.48; 11.3.52). A. G. Rocchini, assr to Gulf Research & Development Co. Corrosion-inhibiting composition comprising a mineral oil solution of a reaction product obtained by heating for 5 min at *ca* 250° F mixed alkenyl-substituted succinic anhydrides, in which the alkenyl substituents contain an average of 10 to 12 carbon atoms, with trimethylamine, triethylamine, triamylamine, triethanolamine, tribenzylamine, tristearyltriethanolamine-triethanolamine-ethylphosphatidic acid, or pyridine.

U.S.P. 2,588,441 (Canada 23.12.48; 11.3.52). F. M. Watkins, assr to Sinclair Refining Co. Water containing as a corrosion inhibitor ammonium, morpholine, or mono*cyclo*hexylamine mahogany sulphonate.

U.S.P. 2,589,114 (10.1.50; 11.3.52). C. A. Murray, assr to The Pure Oil Co. The corrosive effects of ammonium sulphide and hydrosulphide on ferrous and cupreous metal surfaces, for example in cracking units, is minimized by reacting such compounds with formaldehyde.

U.S.P. 2,589,461 (26.9.49); 18.3.52). P. W. Uhl, assr to General Motors Corpn. Corrosion in I.C. engine water cooling systems having aluminium water manifolds is prevented by inserting a copper–copper oxide rectifying gasket between the aluminium manifold and the water passage in the cast iron engine, a layer of tin foil covering each face of the gasket. J. M. S.

Engines and Automotive Equipment

2956. Wear of fuel injection equipment and filtration for compression-ignition engines. A. E. W. Austin and B. E. Goodridge. *Proc. Inst. Mech. Engrs* (*Auto. Div.*), 1950–51, Pt 111, 85–104.—The effect of abrasive particle size on the wear of fuel injection equipment is investigated, and a mechanism of wear is proposed which accounts quantitatively for the wear observed. The particle transmission properties of commonly used filters and of possible alternate filter materials have been measured, and data on the nature and particle sizes of solids in fuels are presented. Estimates of the effect of filters in reducing abrasive wear are made and compared with current service experience in this respect. The choking properties of filter materials are compared using a waxy sludge obtained from marine diesel fuel, and a hypothesis of the choking mechanism is proposed, making it possible to predict choking behaviour from initial resistance and thickness and to assess, by means of a " figure of merit," filter materials of different

particle transmission properties and thickness. The special properties and limitations of paper filters are considered in some detail. J. G. H.

2957. Indirect engine cooling. J. L. Koffman. *Gas Oil Pwr*, 1952, **47**, 188–91.—In this theoretical article the effect of temp and rate of flow on the design and size of heat exchangers is considered. The heat exchanger should be mounted on the side of the engine with oil flowing through the shell and water through the tubes. The water should be cooled by flow through a radiator, and thermostatically controlled. The circuit should be kept separate from any engine-cooling water, and this has the additional advantage that the oil can be warmed before starting in cold weather.

In a worked example the size of heat exchanger is calculated for a 500-b.h.p. engine, the oil circuit of which must dissipate 2000 B.Th.U/min with an oil flow of 10 gal/min. H. C. E.

2958. Flame radiation trials. Anon. *Petroleum*, Sept. 1952, **15** (9), 244–5, 247.—Some of the research carried out at the Royal Netherlands Steelworks at Ijmuiden is described. This work is supervised and directed by national committees from France, Holland, Sweden, and Great Britain. The primary object of the work is to elucidate the mechanism of flame radiation covering investigations on oil, gas, and solid fuels. The experiments with oil fuels have been completed and are described in the article. Each group of experiments is divided into two parts :—

(i) Performance trials, which provide information on the relation between the flame and its surroundings at points along the flame, by measurements made outside the flame.

(ii) Combustion mechanism trials, which show what is actually happening as the fuel burns, by measurements showing the extent of combustion.

An examination of the results obtained from forty-eight performance trials on oil fuels indicates that the radiation in the early part of the flame is mainly affected by the qualitative variables—*i.e.*, by a change of fuel and a change from air to steam as atomizing agent—whereas the tail of the flame is mainly affected by three quantitative variables—quantity of fuel, quantity of atomizing agent, and quantity of combustion air.

Oil burner studies indicate that although there may be small differences between the burners tested, they are unimportant compared with the effects of varying the quantities of atomizing agents. Tests have shown the overriding importance of mixing and of jet momentum. R. E. P.

2959. Development of gas turbines. Anon. *Gas Oil Pwr*, 1952, **47**, 149–53.—A general review of the problems involved in the design, manufacture, and testing of gas turbine installations. A short bibliography is appended. H. C. E.

2960. The pattern of gas-turbine development. F. T. Hague. *Mech. Engng*, Aug. 1952, **74** (8), 627.—A brief history of the gas turbine in Europe and the U.S. is given, and the reasons for British leadership in aviation gas turbines are discussed. Prototype gas turbine power plants were built in England and the U.S. after the war to obtain basic data and operating experience of long-life plant. Future possibilities of the gas turbine are considered, and it is stated that future improvements are more promising for the gas turbine than for any other form of heat engine. It is considered that, in a few years, a high efficiency, compact, low-cost gas turbine, operating at high C.Rs and high temp, without heat-exchanger, will be available. Commercial gas turbine production in Switzerland and England is summarized, and future British projects are outlined. In the U.S., in order to conserve materials and reduce costs, the tendency is to design compressors and turbines with the min number of stages compatible with desirable efficiency ; this is a factor in the lower efficiencies obtained with U.S. plant as compared with European sets. Problems encountered with residual fuel burning plant, and the advantages of the gas turbine in natural gas pipeline pumping are discussed. Seven references. T. T.

2961. New fuel pump and governor. Anon. *Gas Oil Pwr*, 1952, **47**, 153–5.—This pump, manufactured by Simms Ltd., has been designed primarily for small high-speed

C.I. engines of approx capacity 1000 cc/cyl. The quantity of fuel is controlled by a lever projecting from the bottom of the plunger. This engages with a fork clamped to a square control rod, and adjustment is provided by moving the fork along the rod. This arrangement minimizes the effect of wear on calibration.

The pneumatic governor comprises throttle control unit, governor unit, and suction pipes connecting the two. By moving the throttle valve to the closed position an increased suction is created on the engine side of the valve; this suction is transferred to a diaphragm which operates the pump control rod to reduce the fuel delivery. With the throttle in fixed position the engine will run with a speed variation of only 5 to 10% between no-load and full-load conditions.

The construction of the pump and governor is illustrated by several line diagrams.

H. C. E.

2962. Dowtry fuel pump for gas turbines. Anon. *Gas Oil Pwr*, 1952, **47**, 171.—This positive displacement type pump is fitted on gas turbine locomotives, where it delivers 750 gal/hr at 650 p.s.i. A rotor containing radial cyl rotates on a fixed valve shaft. At their outer ends the pistons have pivoted slippers which are rotated within a fixed track ring mounted eccentrically.

Rotation of the cyl and pistons imparts an impeller action to the fuel entering through a duct to the centre shaft, along which it flows to a peripheral port located opposite the high point of eccentricity. The fuel enters the cyl as the piston rises to the top of its stroke, and as the cyl rotates to the low point of eccentricity the piston is driven down, thus compressing the fuel. The cyl then passes over the outlet port, and the fuel is delivered under pressure to the feed line. During a 500-hr test a pump delivered 136,000 gal kerosine at 1000 p.s.i., and subsequent tests showed a delivery drop of only 0·2%.

H. C. E.

2963. Compression ratio and fuel consumption of gas turbines. Anon. *Mech. World*, Aug. 1952, **131** (3397), 62.—Details of the Bristol Olympus and Proteus engines are given. The Olympus has compounded axial compressors, each compressor being driven by its own turbine, the low pressure compressor acting as a supercharger. A thrust of 9750 lb is developed, and the fuel consumption is 0·766 lb/lb thrust/hr. Sea-level static performance of the Proteus III (700 series) is 3320 shaft h.p. plus 1200 lb jet thrust (3780 e.h.p.), fuel consumption 0·62 lb/e.h.p/hr; at 35,000 ft and 350 m.p.h. the figures are 1335 shaft h.p. plus 300 lb thrust (1680 e.h.p.), fuel consumption 0·48 lb/e.h.p/hr. The compressor of the Proteus engine has twelve axial stages and one final centrifugal stage. Eight interconnected combustion chambers, two with igniters, are fitted. Both compressor and power turbines now have two stages, and the compressor turbine blades are air-cooled. A description of engine accessories follows.

T. T.

2964. Recovering jacket heat as live steam. Anon. *Gas Oil Pwr*, 1952, **47**, 177–9.—The deleterious effect of condensation on the cyl walls of I.C. engines is well known, and it has been shown that with cyl wall temps of 100° to 240° C the rate of wear is small and constant, but below 90° C it increases rapidly. To keep the cyl wall temp constant at a level high enough to prevent condensation a new method of engine cooling has been developed.

A pump circulates the jacket water through a "vapour phase unit" at 10 p.s.i. and 240° F; here the pressure is reduced and the water flashes into steam, which is then separated and can be used for low-pressure space heating, etc. If the steam is not recoverable as condensate, make-up water must be added. The advantage of this system is that the engine temp is automatically controlled, for any variation in the engine load appears as a variation in the amount of steam generated.

It is stated that from a 500-b.h.p. engine, which could drive a 350-kW generator, a total of 1350 lb steam can be obtained per hr, equivalent to 450 kW of electrical power.

H. C. E.

2965. Diesels at the Paris Fair. Anon. *Gas Oil Pwr*, 1952, **47**, 165–7.—A short description of some of the Continental diesel engines on show in Paris recently.

H. C. E.

2966. Admiralty Standard Range II [Diesel] engine. Anon. *Gas Oil Pwr*, 1952, **47**, 156–8.—This Y.H.A. series of engines has a power range from 200 to 800 b.h.p. The cyl dimensions are 7 inches bore and 7½ inches stroke, and the cyls are arranged in two banks set at 60° angle. The Al-alloy pistons carry three compression and two scraper rings, and the pistons can be removed through the crankcase doors without dismantling the cyl heads. The latter are fitted with four valves.

Details of the engine construction are given.

Pressure lubrication is applied to all working parts and to the hydraulic servo flywheel governor, which is actuated by engine oil pressure, thus providing a safety device if the oil supply fails. Two Napier pressure chargers are fitted to the twelve-cyl unit. H. C. E.

2967. The turbo-charged Doxford engine. Anon. *Motor Ship*, Aug. 1952, **33** (389), 188.—A report, with illustrations, of tests carried out by Doxford with a three-cyl turbo-charged engine (this being half the six-cyl engine which is the size which will generally be pressure-charged) with a 600 mm cyl bore and combined stroke of 2000 mm, and with the aim of supercharging so that the output is 50% more than normal rating. Fuel consumption of 0·325 lb/b.h.p. hr, and mechanical efficiency approaching 95% were recorded. U. M.

2968. The latest Stork double-acting engine. Anon. *Motor Ship*, Aug. 1952, **33** (389), 172.—Considerable developments have been made in this engine since it was first built in 1932, and in its latest form it is constructed in three standard sizes which provide a range of from 5000 to 10,000 b.h.p. in from six to nine cyl. A feature of the engine for many years has been the use of chromium plated cyl liners. Experience has shown that wear is thereby much reduced and the cyl liner is maintained in a new condition throughout the lifetime of the layer. When the layer is worn a new one can be deposited on the old liner. A full description with illustrations is given of an engine of eight-cyl type, of 720 mm dia and 1200 mm stroke, differing from the standard engine in that it does not drive its own scavenge pump. U. M.

2969. New design of Sulzer medium-speed engine. Anon. *Motor Ship*, Aug. 1952, **33** (389), 190.—Description, with illustrations, of prototype of two units, for installation in M.V. *Middlesex*, now under test. Unit is of crosshead type, largely of fabricated steel construction, and is intended to run on boiler fuel. The unit is rated at 500 b.h.p. per cyl at 225 r.p.m., under which conditions the b.m.e.p. is 70·5 p.s.i., but it will take an overload up to more than 6000 b.h.p. at 250 r.p.m., when the b.m.e.p. is about 78·25 p.s.i. However, when installed in the *Middlesex* the two engines will maintain a continuous output of 9000 b.h.p. at 225 r.p.m. U. M.

2970. New Petter marine engine. Anon. *Gas Oil Pwr*, 1952, **47**, 158.—The BM engine is available as two-, three-, or four-cyl units giving a power range of 16¾ to 31¼ b.h.p. at 1500 r.p.m. The cyls are of 110 mm bore and stroke. The direct injection system and hemispherical combustion chamber in the piston crown are designed for low fuel consumption and easy starting.

Lubricating oil and water circulating pumps are provided; fuel feed is normally by gravity. H. C. E.

2971. A.E.C. lightweight railcar demonstrated. Anon. *Gas Oil Pwr*, 1952, **47**, 182.—The power railcar is fitted with an underfloor horizontal engine which has six cyl of dimensions 120 mm bore and 140 mm stroke and provides 125 b.h.p. at 1800 r.p.m. The tractive effort varies from 4700 lb at 10 m.p.h. in first gear to 1110 lb at 45 m.p.h. in fourth gear. The standard set comprises two powered and one non-powered cars. H. C. E.

2972. Patents. U.S.P. 2,587,842 (28.11.49; 4.3.52). C. W. Hall, assr to M. S. Losey. Rotary valve with liquid fuel injection port for I.C. engines.

U.S.P. 2,588,136 (12.11.47; 4.3.52). M. Mallory. Charge control valve mechanism for I.C. engines.

U.S.P. 2,588,481 (13.12.44; 11.3.52). M. E. Chandler, assr to Niles-Bement-Pond Co. Fuel injector pump for multi-cyl I.C. engine.

U.S.P. 2,588,546 (8.8.46; 11.3.52). L. Lee, assr to Niles-Bement-Pond Co. Fuel injection control system for I.C. engines.

U.S.P. 2,588,547 (27.1.48; 11.3.52). L. Lee, assr to Niles-Bement-Pond Co. Fuel injection control system for I.C. engines.

U.S.P. 2,588,952 (7.12.45; 11.3.52). J. C. Baisch, assr to Carter Carburetor Corpn. Fuel supply system for I.C. engines.

U.S.P. 2,588,961 (28.10.46; 11.3.52). H. A. Carlson and D. E. Alford, assrs to Carter Carburetor Corpn. Choke control.

U.S.P. 2,589,089 (5.5.49; 11.3.52). R. W. Johnson. Motor control system for fuel pumps.

U.S.P. 2,589,154 (2.10.47; 11.3.52). D. M. Smith, assr to McQuay-Norris Manufacturing Co. Piston ring assembly.

U.S.P. 2,589,958 (France 28.1.48; 18.3.52). G. Petit. Variable compression ratio I.C. engine involving a mounting to vary the position of the crank shaft relative to the cyl block and a fluid jack to actuate the mounting.

U.S.P. 2,590,009 (7.3.47; 18.3.52). J. A. Hannum, assr to Borg-Warner Corpn. In an aircraft fuel-burning prime mover using a liquid mixture of a fuel and a nitro aliphatic oxidant the proportion of the oxidant in the mixture is increased with increasing altitude of the aircraft.

U.S.P. 2,590,135 (18.5.49; 25.3.52). J. C. Slonneger, assr to The Continental Supply Co. Safety device for cooling systems for I.C. engines. J. M. S.

Safety Precautions

2973. Explosion pressures in electric motors. Anon. *Petrol. Times*, 19.9.52, **56** (1438), 798.—The Safety in Mines Research Establishment Report No. 38, "The pressure generated during explosion inside a core cooled motor," by H. Staples, is outlined. G. A. C.

2974. The control of oil storage tank fires. J. H. Burgoyne. *Petrol. Times*, 5.9.52, **56**, 759.—A summary of the practical conclusions drawn from papers published in *J. Inst. Petrol.*, 1947 and 1949, upon the burning behaviour of a wide range of petroleum products and appropriate methods of control. Use of foam and of agitation to extinguish fires are dealt with. G. A. C.

2975. Nuisance control and U.K. refineries. Anon. *Petrol. Times*, 5.9.52, **55**, 763.—The 87th Annual Report concerning the year 1950 of the chief inspectors on alkali, etc. Work is reviewed, with reference to the increasing oil refining capacity of the U.K., the fume emission problem, and measures in hand to minimize the effect on local amenities. G. A. C.

2976. Patent. U.S.P. 2,588,312 (31.8.49; 4.3.52). R. P. Walker, assr to Standard Oil Development Co. Foam distributor nozzle for distributing fire foam. J. M. S.

Miscellaneous

2977. A motorist looks at the oil industry. Lord Waleran. *I.P. Review*, 1952, **6**, 281.—Starting from the invention of the first motor car co-operation between the motor and oil industries is traced. Research into the causes of "knock" has led to the production of better fuels, and engine makers have been able to give engines greater power and efficiency. The writer points out that the U.K. is still using only 70–72 O.N. (Pool) Spirit, whilst elsewhere higher grade materials enable higher C.R's to be employed. The amount of taxation paid in the U.K. is also very high, but, despite this, petroleum spirit is more expensive in many European countries. Expansion of the

U.K. refining capacity should expedite development in the future, and the author hopes for efforts by motor manufacturers to reduce petrol consumption. Brief mention is made in turn of the gas turbine car, the retailing of petroleum in the U.K., and of the use of petroleum bitumen for the making and upkeep of roads. R. H.

2978. Canada's oil industry. S. M. Blair. *J. Roy. Soc. Arts*, 1952, **100**, 640–63.—The coal industry, natural gas, Athabaska oil sands, and Western oilfields are surveyed and discussed from the historical development and production aspects. Statistical details of the reserves, and rates of production of the Western fields are given. Nature and properties of the crude oils, locations of the Canadian refineries, output of products, market demands, and transport of products are described. The three requirements of the industry—manpower, supplies, and capital—are widely discussed. The Dominion Government's oil development control and transport by existing and prospective pipelines in Canada and to possible markets in America are discussed in detail. Canadian production from the west is now approaching one-half the country's total requirements, and will soon be satisfying all the nations readily accessible markets. W. H. C.

2979. Are we certain of our liquid fuel supplies? A. Lassieur. *Chim. et Ind.*, 1952, **67**, 978–83.—Rapid review of sources of pet available to France. The position although assured at present, is considered precarious for the future, largely due to political instability of Middle East, and the development of alternative sources of liquid fuel (coal, alcohol) is urged. V. B.

2980. French petroleum industry. L. Chové. *Chim. et Ind.*, 1952, **68**, 237–42.—Brief historical sketch and summary of present position. It is forecast that increasing fuel oil requirements may cause excess availability of gasoline, as a by-product of fuel oil production, and tax reduction is suggested to stimulate sales of former. V. B.

2981. Economic and financial problems of Italian hydrocarbons, III—Productive possibilities, requirements, and consumptions of natural gases. L. Faleschini. *Proc. 3rd World Petrol. Congr.*, 1951, **1**, 286–95.—In order to obtain a general view of the regional situation of the gas-extraction industry in Italy, many data are given regarding the production, transport, and consumption of hydrocarbons in that country. These data chiefly concern five main areas in the Northern Regions, viz.: Piemonte, Liguria, Lombardia, Emilia, and Veneto. A table is given showing their separate percentage distribution, and for the whole of Northern Italy. The theoretical and practical problems of the hydrocarbons industry are closely linked, and therefore, it is remarked, they should be considered together in order to understand the solutions adopted in Italy. G. S. S.

2982. A national fuel policy for the United Kingdom. Anon. *Petrol. Times*, 19.9.52, **56**, 803.—The "Report of the Committee on National Policy for the Use of Fuel and Power Resources" is reviewed. Present and future demand, oil supply prospects, dieselization, and better petrol are some of the points covered. G. A. C.

2983. The production of elemental sulphur from Jumping Pound natural gas. L. T. Munn. *Canad. Min. metall. Bull.*, Aug. 1952, **45** (484), 487–8.—A typical analysis is given of the natural gas obtained from the Jumping Pound field, which is situated about 20 miles west of Calgary. The Shell Oil Co. of Canada's gas treating plant and sulphur extraction unit and their operation are described. The sulphur plant is designed to produce 30 tons/day of sulphur with a purity of 99·9%. The liquid sulphur from the plant is distributed over the earlier made product which has solidified. When the vat is full, the thin metal walls are removed and shot-holes are drilled in the block, one face of which is blasted off, causing the material to be shattered sufficiently for handling and transport. Care has to be taken when blasting owing to the combustible nature of sulphur and the risk of explosion of sulphur dust and air. W. H. C.

2984. What the process engineer hopes to find in the accounting records. W. L. Nelson. *Oil Gas J.*, 25.8.52, **51** (16), 123.—Detailed rather than total costs, records

of hours of each kind of labour, quantities of materials, utilities, and oil stocks, information on qualities of utilities, and close association between operating and accounting departments are called for in this article. G. A. C.

2985. A good waste-disposal programme makes sense . . . and profits. W. C. Douce and J. Wood. *Oil Gas J.*, 8.9.52, **51** (18), 100.—Methods of reducing a small refinery's waste to a min are outlined. Liquid, oil-containing, and chemical wastes, solid-bearing systems, gaseous products, smoke, and catalyst dust are dealt with. G. A. C.

2986. Persia threatens to break diplomatic relations with Britain. Anon. *Petrol. Times*, 19.9.52, **56**, 790.—Dr Moussadek's statement of 16 Sept. 1952, to the Persian Majlis is given, and letters in *The Times* from Mr R. Stokes and Mr W. J. A. Brown quoted in full. G. A. C.

2987. Israel Petroleum Bill No. 5712—1952. Anon. *Petrol. Times*, 19.9.52, **56**, 791.—Article concludes the draft terms of the Bill recently passed by the Knesset. Pts 1 and 2 of the Bill were given in the last issue of this journal. G. A. C.

ADDITIONS TO THE LIBRARY

Fuel Research 1951. Fuel Research Board. London: HMSO, 1952. Pp. 60 + v. 2*s*. 6*d*. (by post 2*s*. 7½*d*.).

The report of the Director of Fuel Research, which occupies most of this book, includes a separate chapter on oils and chemicals in which is recorded work done at Greenwich on : (i) the Fischer–Tropsch synthesis; (ii) flow properties of residual petroleum fuel oils; and (iii) removal of sulphur from residual fuel oils. In regard to (ii) results are reported of work which is continuing on the changes in oil structure which lead to alterations in its viscous properties. Under (iii) a study is being made of the extent to which desulphurization of residual fuel oils can be effected by simple treatments.

Report of the Committee on National Policy for the Use of Fuel and Power Resources. London: HMSO, 1952. Pp. 242 + v. 6*s*. 6*d*. net.

Properties of the Principal Fats, Fatty Oils, Waxes, Fatty Acids and their Salts. M. P. Doss. New York: The Texas Co., 1952. Pp. 244. $5.00.

In this new publication by M. P. Doss, technical librarian of The Texas Company, are listed the significant properties of about fifty fats, fatty oils, and waxes, over 800 aliphatic acids, and approximately 1750 salts ranging from aluminium to zirconium. This compilation, the value of which is inestimable, is the result of ten years' search of published and unpublished data, and over 1350 literature references are cited.

Useful conversion tables and charts are appended for temperature; API degrees, sp. gr., and lb/gal; viscosity; and colour.

Interchangeability of Oil Gas and Natural Gas. D. L. Nichol, R. A. Brown, and H. R. Linden. Chicago, Illinois: Institute of Gas Technology, 1952. Pp. 28 + iv. $2.50.

An interim report on the combustion performance of a high B.Th.U. oil gases when substituted for natural gases in seven selected critical burners. There is also a study of two natural gases used in place of oil gases in the same burners.

A Symposium on Gear Lubrication. London: Institute of Petroleum, 1952. Pp. 198. 15*s*.

Report of a meeting held by the Institute on 13 February 1952. Part I on lubrication of gears contains papers by A. Cameron, G. I. Finch and R. T. Spurr, F. T. Barwell and A. A. Milne, H. D. Mansion, Ewen McEwen, E. A. Smith, and L. S. Evans and R. Tourret. Part II, on the testing of gear lubricants, includes papers by the IP Mechanical Tests of Lubricants Panel, J. R. Hughes, H. L. Bingham and J. G. Withers, R. D. B. Stone, J. Greenwood and R. W. Morton, A. Towle, H. J. Watson, and J. E. Styles and A. T. Wilford.

Proceedings of Thirty-first Annual Convention Natural Gasoline Association of America. Tulsa, Okla : The Association, 1952. Pp. 152.

This convention was held during the period 30 April–2 May 1952. Altogether there were six forums on corrosion, extraction and separation, gathering systems, history, traffic, safety and personnel, fractional analysis, operations, and liquefied petroleum gas. There were also several addresses of general interest.

Tables of Chemical Kinetics. Homogeneous Reactions. U.S. Department of Commerce, National Bureau of Standards Circular 510, 1951. Washington, D.C. : Superintendent of Documents, 1951. Pp. 729 + xxiv. $4.00.

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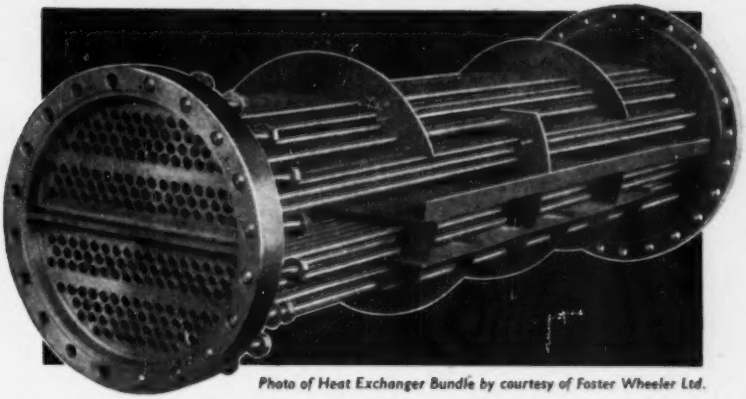

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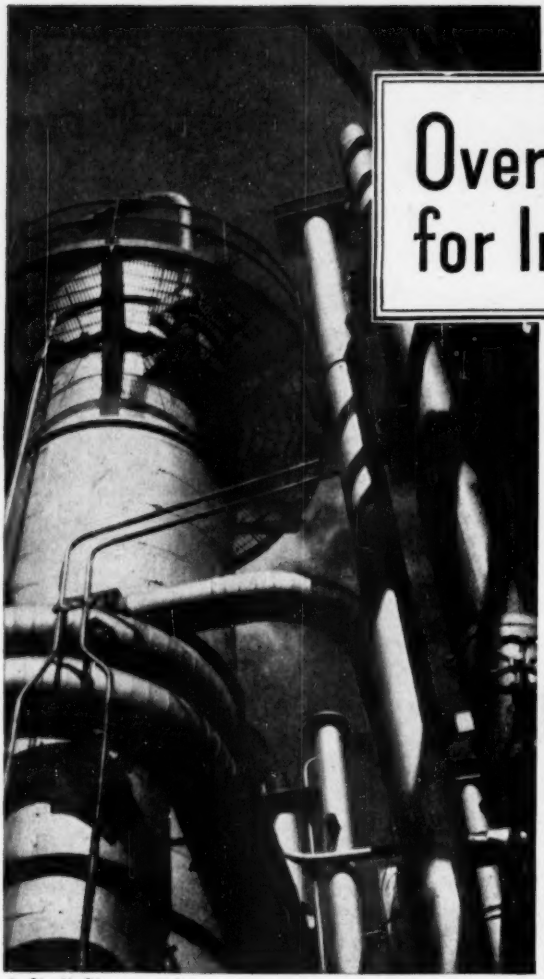

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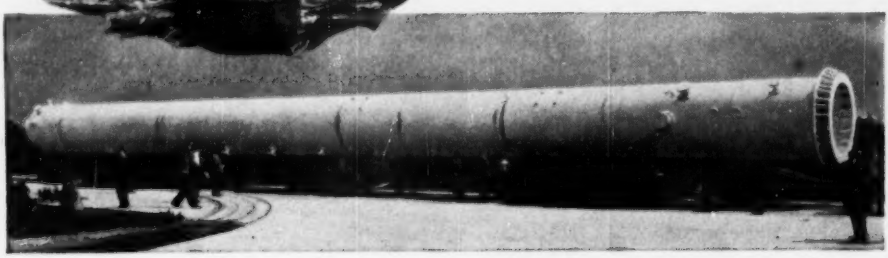

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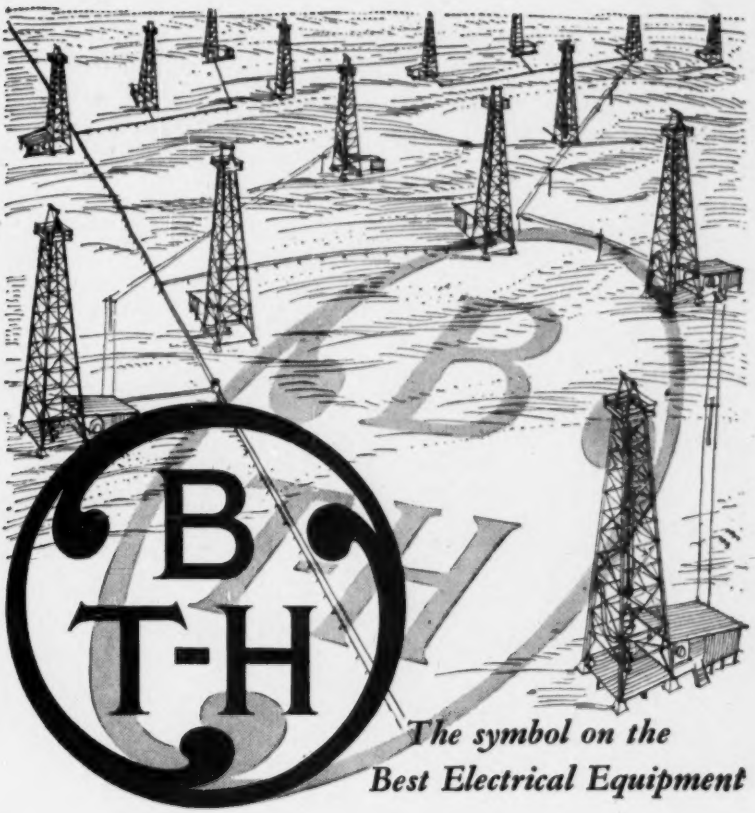

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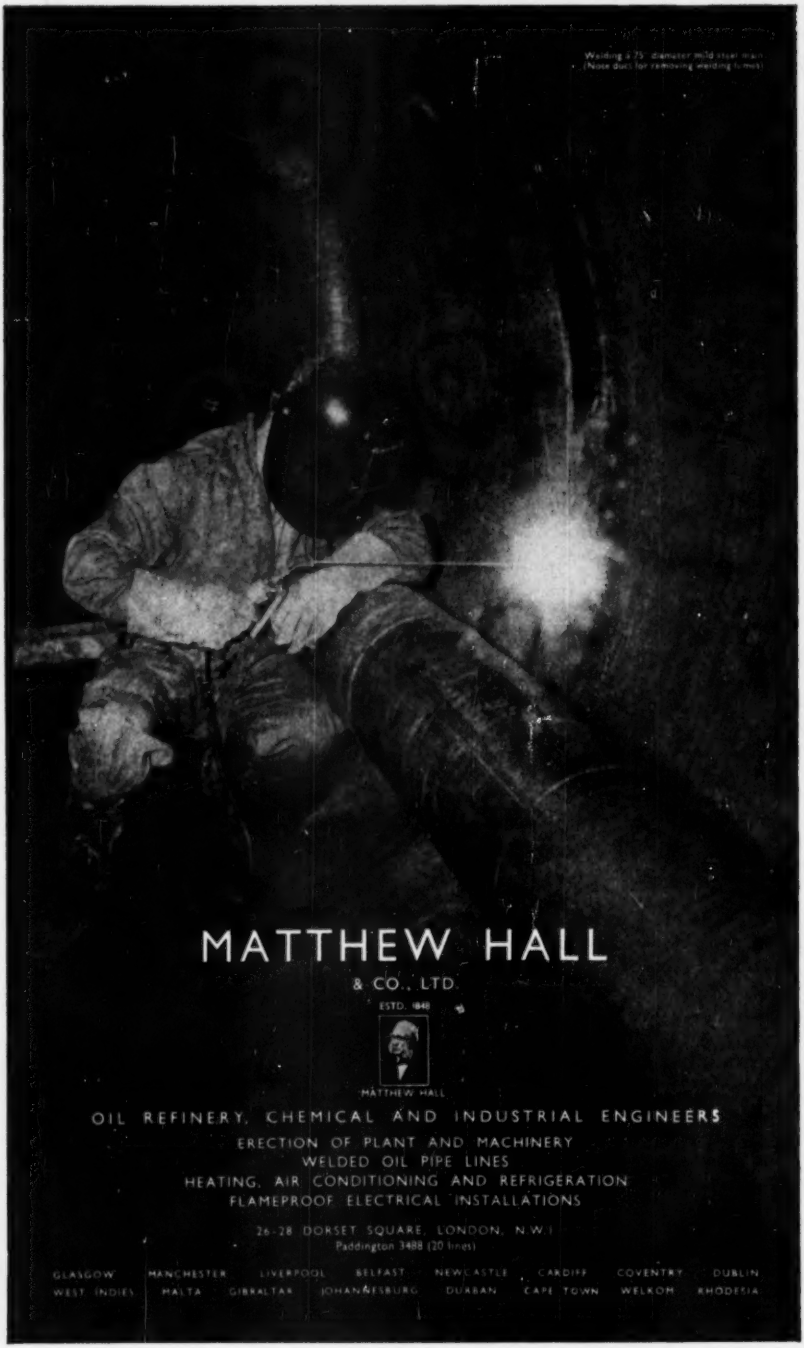
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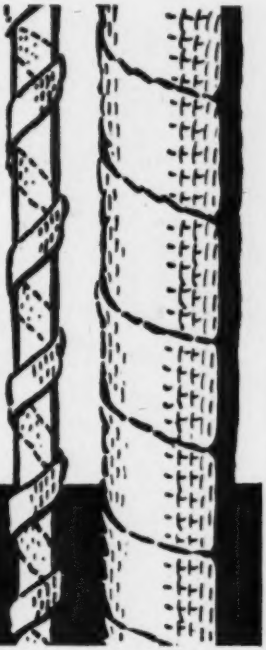

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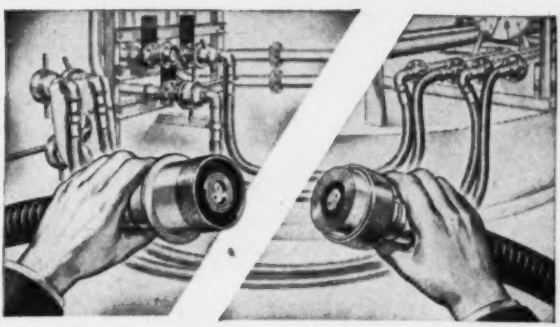

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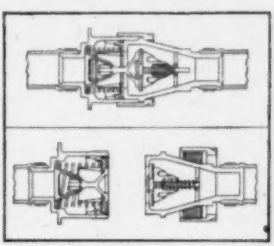

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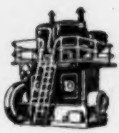

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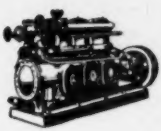

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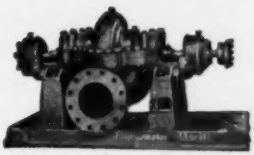

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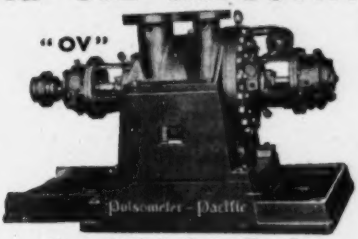

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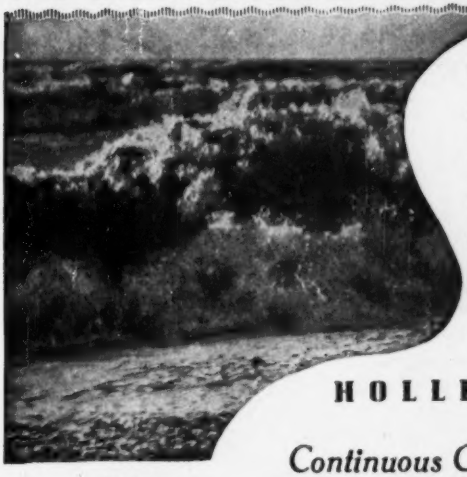

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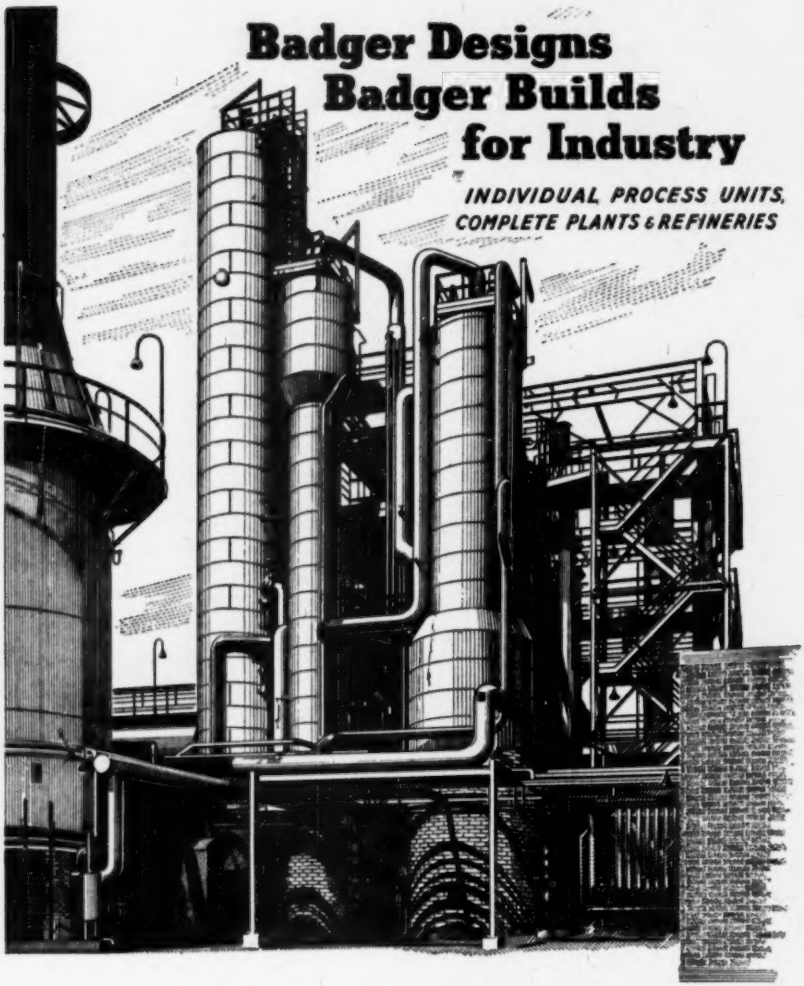

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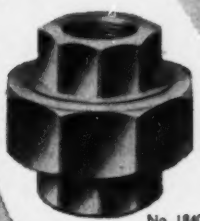

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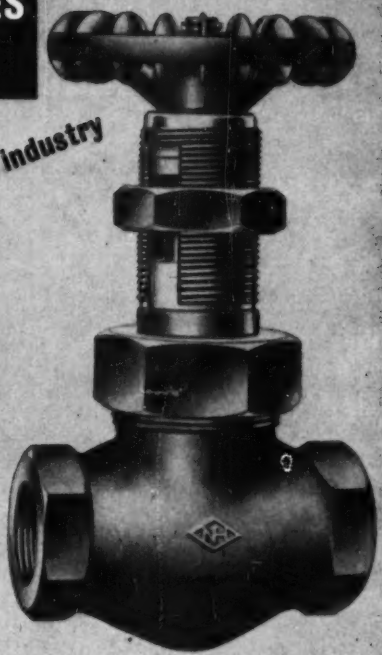

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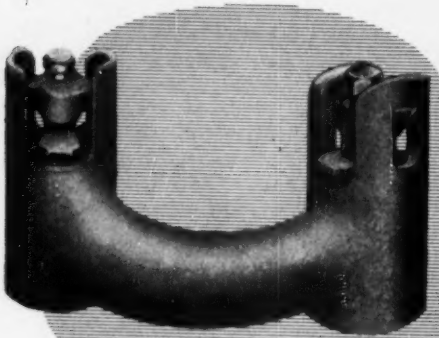

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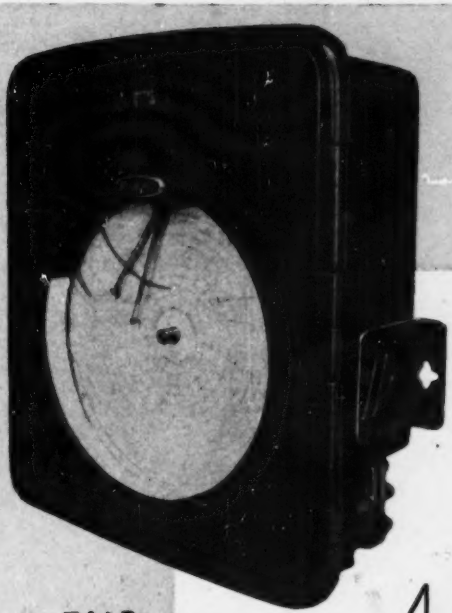

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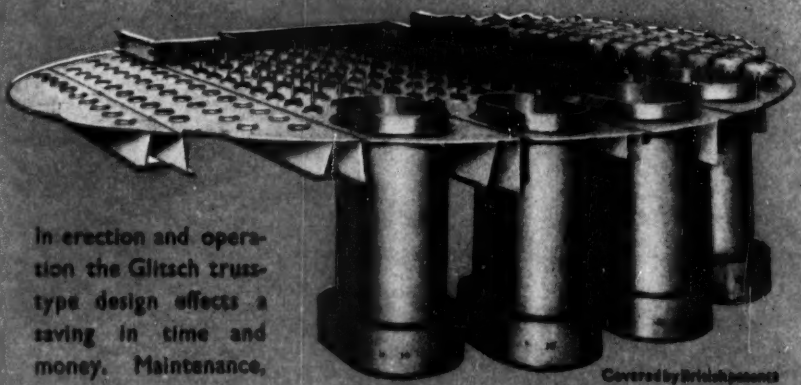

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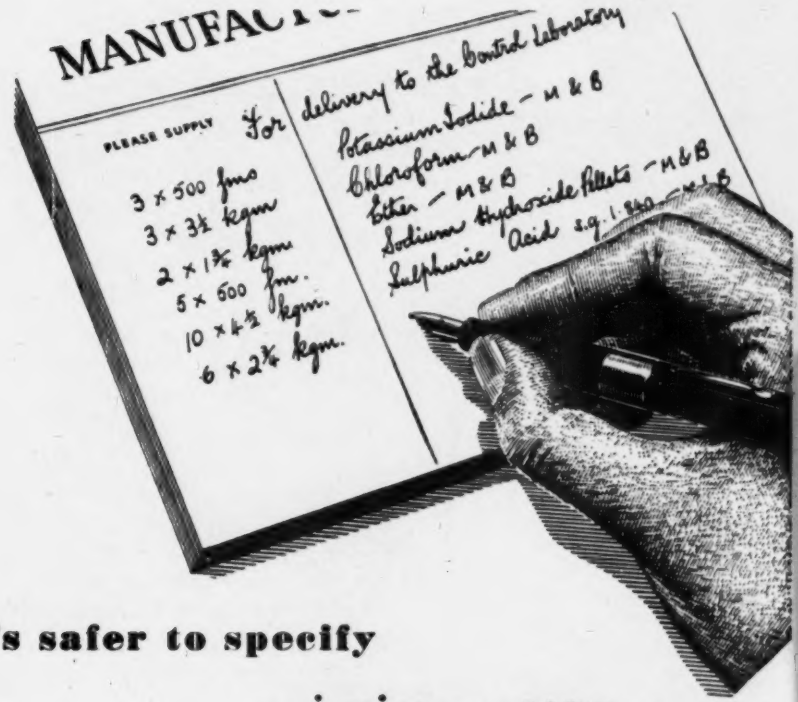
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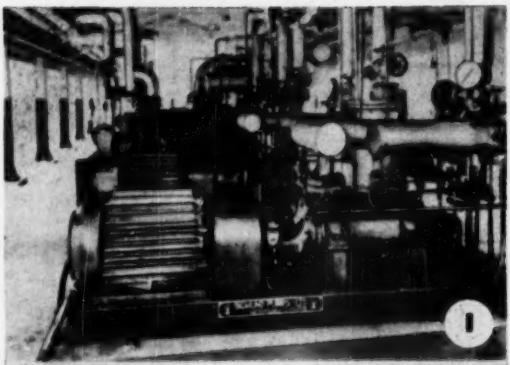

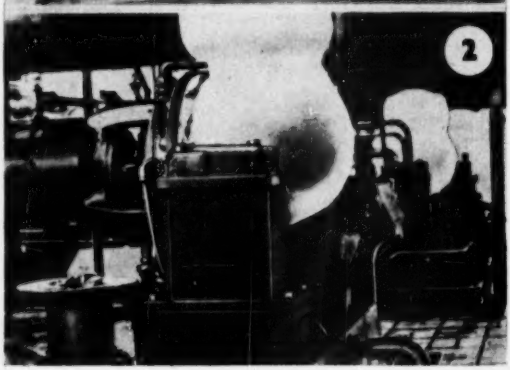

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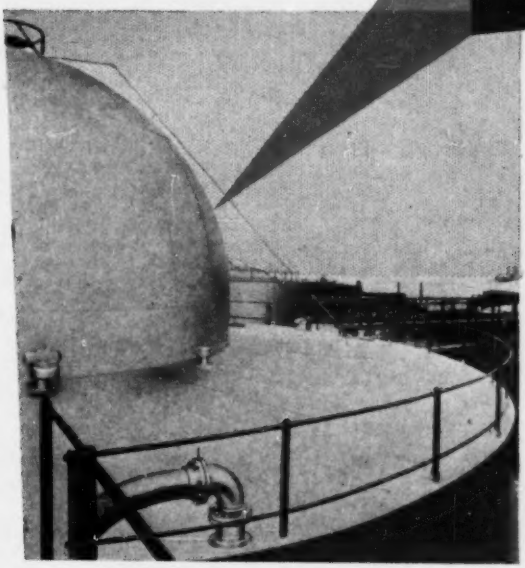

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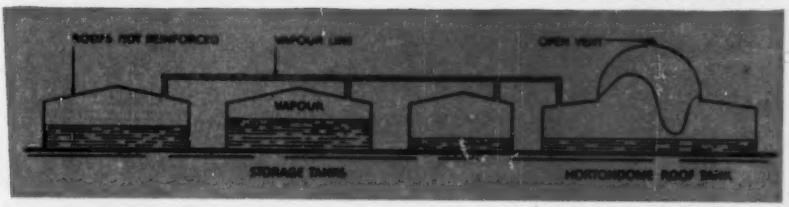

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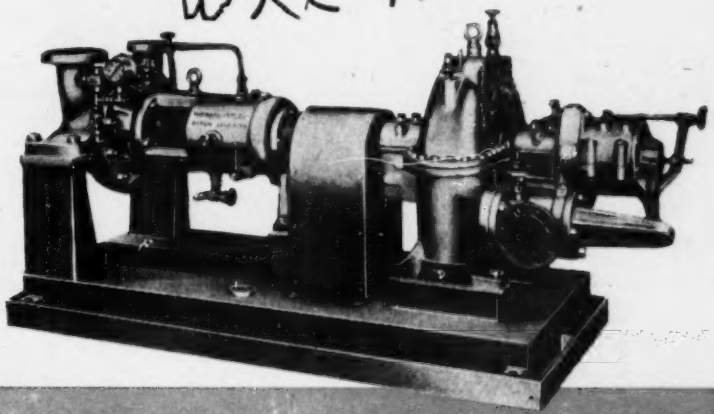

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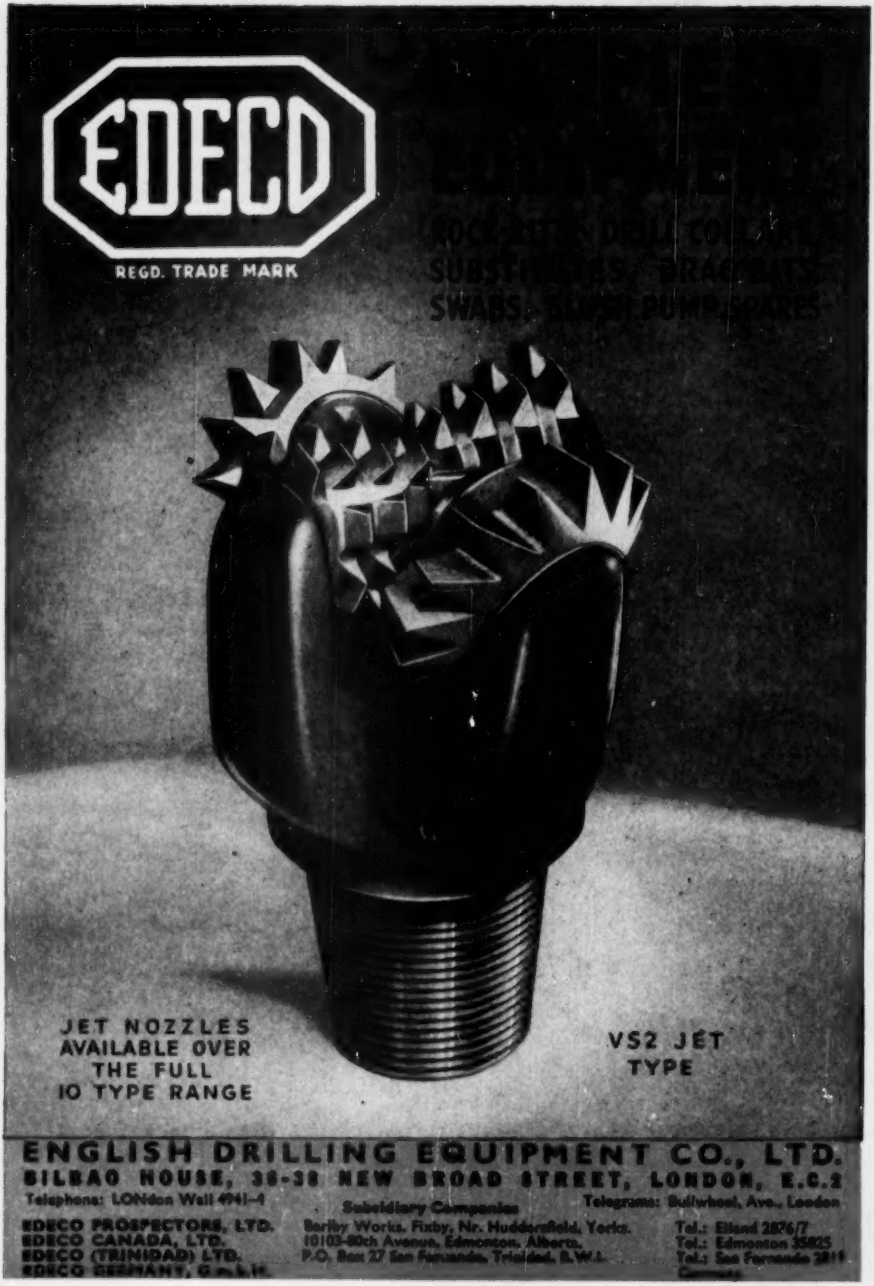
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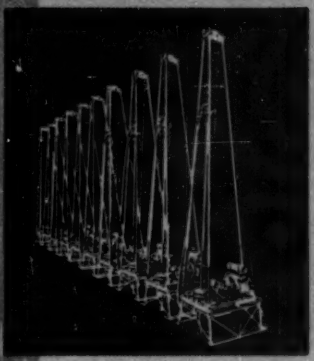

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